EFFECT OF SOIL FUMIGATION ON SOIL NITRIFICATION AND TOMATO PLANT BEHAVIOR

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A Dissertation Presented to the Graduate Council of
The University of Florida
In Partial Fulfilment of the Requirements for the
Degree of Doctor of Philosophy

UNIVERSITY OF FLORIDA
FEBRUARY, 1952

91.58 H216 c.2 27922 10/24/52 AE52

ACKNOWLEDGMENTS

The author wishes to acknowledge with deep gratitude the kindly advice of Dr. V. F. Nettles, Associate Professor of Horticulture, under whose guidance and continuous help this study was conducted.

He wishes to express his thanks and sincere appreciation to all members of the Horticulture Department in the Florida Agricultural Experiment Station whose assistance and encouragement were a constant source of inspiration.

He particularly acknowledges the kindly advice and criticism of Dr. H. S. Wolfe, Head Professor of Horticulture, Dr. G. J. Stout, Professor of Horticulture, Dr. L. C. Hammond, Assistant Professor of Soils, Dr. V. J. Senn, Assistant Professor of Chemistry, Dr. S. G. Gilbert, Associate Plant Physiologist and Dr. G. D. Thornton, Associate Microbiologist.

The author also wishes to thank Dr. C. B. Hall, Assistant Professor of Horticulture who went through the manuscript and Mr. James Montelaro for his help.

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EFFECT OF SOIL FUMIGATION ON SOIL NITRIFICATION AND TOMATO PLANT BEHAVIOR

INTRODUCTION

In the short space of a few years, soil fumigation has become the most practical treatment for fields infested with root-knot nematodes. Root-knot nematode is a disease caused by the invasion of a microscopic nematode worm Heterodera marioni (Cornu, 1879) Goodey, 1932, (syn. Meloidegyne spp.) as mentioned by Goodey (14). The larva, which can live a variable length of time according to the environmental conditions, makes its entry through the roots and lives parasitically in them. The complete life cycle of this parasite is given by Tyler (47), Steiner (42), Linde et al. (22), Elsea (10) and many others. The root-knot nematode is distributed extensively through the tropics, subtropics and temperate regions, and its occurrence in the greenhouse everywhere makes it one of the common agricultural pests. This disease attacks a wide variety of economic plants in different degree. Steiner (42) states that over 1,700 different plant species are known to be attacked by the root-knot nematode. However, they exhibit a wide variation in their susceptibility; some suffer severely from slight attack, while other species are tolerant. Buhrer et al. (3) presented a list of plants attacked by the root-knot nematode. Neal (27) has mentioned that the disease was known in Florida as early as 1805; however, the organism which causes the root-knot was not discovered until 1879. In 1889 it was definitely established as occurring in Florida. Watson (53) gives a list of plants, including most of the farm and garden crops commonly grown in Florida, in the approximate order of their susceptibility to damage from root-knot nematodes. The tomato is one of the most susceptible crops and this can result in great loss. Plate 1 shows roots of tomato plants badly infested by root-knot nematodes. These plants were grown on the Florida Agricultural Experiment Station farm in Arredonda loamy sand. Steiner (42) mentioned the presence of root-knot in all sections of the state and the fact that it is very destructive where sandy and peaty soils prevail. He estimated the damage caused by root-knot nematodes in the State of Florida to be several million dollars annually. Hume (18) stated that the extent and economic significance of the nematode problem in Florida is one of the most serious to be found anywhere in the South.

In Florida, as well as other parts of the world, many investigations have been carried out to test the effect of the new soil fumigants on the control of the root-knot nematode and other plant diseases. The efficient control of root-knot nematodes through the use of new soil fumigation materials has often resulted in remarkable increase in plant growth and higher yield, as reported by Volk (48), Steiner (42), Kidson and Stanton (19), Peters (33) and many others.

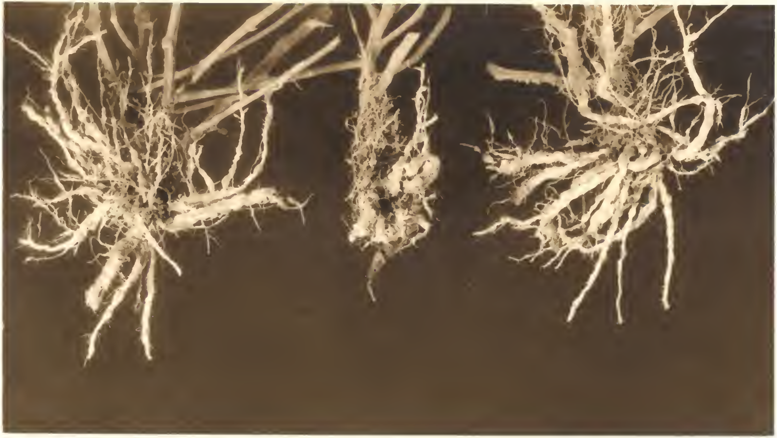

PLATE I. Heavy Infestation on Root-Knot Nematode on Tomato Roots Grown in Arredonda Loamy Sand.

The work here reported was a study of three phases of soil fumigation, conducted in cooperation with the Florida Agricultural Experiment Station. In Part I an attempt was made to study the effect of some new soil fumigants on the nitrifying soil organisms in Arredondo loamy sand. Nitrification has been known for a long time to be one of the important biological processes involved in soil fertility.

Part II was designed to investigate further, in a greenhouse study, the results obtained from Part I. The work was planned to study the effects of some soil fumigants on the absorption of nitrogen by tomato plants when supplied with different sources of nitrogen. Potassium and magnesium at different levels were also included in this work because of their close relation to nitrogen nutrition and their use in fertilizers. This part of the work was a chemical study of plant leaves for the above mentioned minerals and calcium, in order to determine the effect of soil fumigation on the content of these elements in tomato leaves. This phase of the study was also designed to study the effect of the different interactions between soil fumigants, source of nitrogen, and levels of potassium and magnesium on the total nitrogen, potassium, magnesium, and calcium content of tomato leaves.

Part III was principally a study of the effect of the soil fumigants on the yield and quality of the Rutgers tomato under field conditions. The tomatoes were supplied with different sources of nitrogen and two levels of potassium and magnesium in the fertilizer.

REVIEW OF LITERATURE

In the past, root-knot nematodes have been kept under control, to some extent, by certain agricultural practices. Plowing, harrowing and other cultivation practices were some of the operations that helped reduce the noxious nematodes in the soil. This is accomplished by exposing the nematodes to the sun and drying by wind. Crop rotation, also, has long been recognized as a good cultural practice for the rduction of nematode population by starvation and was recommended by Shaw (38), Tyler (47), and Steiner (42).

Mulching was also found to be effective to some extent in controlling root-knot nematodes, as stated by Watson (54). He mentioned that piling dead grasses, weeds, and leaves around the long lived perennials such as figs, roses, and peaches, and also vegetable crops including okra, peas, lettuce, and tomatoes, resulted in good control of root-knot nematodes. The explanation of the effect of mulching on the reduction of nematode population has been discussed by many investigators. Linford et al. (23) found that the decomposition of large amounts of organic matter in Hawaiian soils was associated with a reduction of galls on roots of cowpeas. He stated that the decomposition of organic matter results in increase of several biological forms destructive to nematodes, such as nema-trapping fungi, predaceous nematodes, and predaceous mites. These organisms attack various types of nematodes, destroying the larvae of the root-knot type and other free-living nematodes. Linford and Oliveira (24) also found a number of enemies of root-knot nematodes. He reported the finding of 52 enemies of this organism, some of which are nema-trapping fungi.

Various methods of soil sterilization have been used for controlling the root-knot nematodes. Godfrey and Young (13) state that heat was probably first employed by burning brush or straw on the surface of the ground, but it was ineffective as the treatment did not penetrate deeply enough into the soil. In greenhouses, partial sterilization of the soil by heat gave good results in controlling nematodes and other soil-borne diseases and was recommended by many workers; it was rated first by Taylor (45). Methods of applying live steam and drenching with hot water were developed a long time ago and were recommended in commercial greenhouses, as pointed out by Newhall et al. (32), Taylor (44), Howard et al. (17), and others.

Many chemicals have been tested for their nematocidal properties. Watson (52) stated that calcium cyanamide thoroughly mixed with soil which is promptly and thoroughly irrigated will so greatly reduce the number of nematodes present as to make the growing of susceptible plants profitable. He further stated that, because of the high cost of the treatment, the use of this method for controlling nematodes would probably be limited largely to land on which particularly valuable and highly susceptible crops are raised.

Such lands are seedbeds and truck patches where the most intensive methods of cultivation are practiced. Miller (26) reported that dichloroethyl ether was very effective in controlling root-knot nematodes in okra plants grown in sandy soil. He also mentioned that good results for root-knot nematodes were obtained by soil treatment with ethylene dichloride. Carbon disulphide is another material which was found effective in root-knot nematode control and was recommended by Guba (15). Other materials tested and found to have merit in root-knot nematode control are various organic mercury compounds, cyanide compounds, sulfuric and other acids. All soil drench treatments require large amounts of water for adequate distribution of the sterilizing agent through the soil, and a long period for drying of the soil is required before planting. Most of these chemicals, due to their high cost and toxic effects on humans, are limited in their use.

Soil sterilization by fumigation was first discovered in 1920 as reported by Roark (36). Chloropicrin, an easily vaporized liquid, proved to be fatal to the root-knot nematodes when a small amount was injected into the soil. Soil fumigation had a distinct advantage, in that only relatively small quantities of the chemicals are needed since contact with the soil organisms is obtained by diffusion of the gas. Roark (36) and Gersdorff (11) have supplied a complete bibliography on all phases of the work with chloropicrin until

1930. Chloropicrin as a soil fumigant for controlling root-knot nematodes and other soil-borne diseases was extensively tested by many workers, such as Newhall and Bear (29), Newhall and Stark (31), Taylor (44, 45), Young (55), Chitwood (5), Godfrey (12),and many others. Results obtained by these investigators showed that chloropicrin is a good control for root-knot nematodes and some other soil-borne diseases. However, chloropicrin has certain restrictions that limit its use. These restrictions are its high cost, difficulty in handling, toxicity to man, and its corrosive action on metals.

Methyl bromide, a non-inflammable and non-corrosive soil fumigant, was first discovered to be effective in controlling root-knot nematodes in France in 1934, as mentioned by Newhall (30). He also stated that Lear found that methyl bromide possesses rapid penetrating power. Godfrey and Young (13) have drawn attention to the rapid penetration of methyl bromide into unrotted galls. The advantage of this to a greenhouse grower whose crops must often follow in quick succession is considerable.

During the second World War, allyl alcohol was made in large quantities as one step in the manufacture of plastic from petroleum. A by-product of this process containing approximately two-thirds dichloropropene and one-third dichloropropane was announced by Carter (4) to have the same fatal effect on root-knot nematodes as chloropicrin.

Although it is less disagreeable to handle than chloropicrin and much cheaper, the propene-propane mixture does not kill as large a variety of pests as chloropicrin. However, its ability to control nematodes and some insects in the upper layer of the soil makes it very useful in treatment of vast areas of root-knot infested soil. The propene-propane mixture was very widely investigated in many parts of the United States and other parts of the world. Results obtained by the investigations of Newhall et al. (32), Allen and Raski (1), Volk (47), Clark and Myers (7), Clayton and Ellis (8), and many others showed that its use in certain sections of the country has brought back into profitable production many thousands of acres of land heavily infested with root-knot nematodes, but otherwise good soil. The propene-propane mixture is sold commercially under the names of D-D and Dowfume N.

The latest rivals of propene-propane mixtures are certain products containing the odorless, non-inflammable, non-corrosive, volatile hydrocarbon, ethylene dibromide. It is being put on the market under many names. Like D-D, these fumigants containing ethylene dibromide are used mainly for the control of root-knot nematodes and cannot be depended upon to kill weed seed or fungi. They are among the lowest in cost, and the easiest and safest to handle of any of the soil fumigants yet developed.

Ethylene dibromide and propene-propane mixtures, because of their practical application on vast areas, have been tested extensively in different types of soils. Kincaid and Volk (21) stated that soil fumigation with propene-propane mixture and ethylene dibromide have been rapidly accepted by growers of shade tobacco in Florida, to the extent that about three-fourths of the acreage of the 1948 crop was fumigated. Different methods of application, forms of equipment and dosages in different types of soils with several crops were discussed by Newhall et al. (32), Allen and Raski (1), Nettles (28), Strand (43), Carter (4), Townsend (46), Clark and Myers (7), and many others. All those workers reported that the propene-propane mixture and ethylene dibromide, when properly used, gave good commercial control of root-knot nematodes and increased yield.

EXPERIMENTAL WORK

PART I. Effect of Soil Fumigation on Soil Nitrification

Materials and Methods

The first experiment carried on to study this phase was conducted under controlled conditions. An indirect method was used in this study, in that the amounts of nitrates converted by the nitrifying soil organism were measured, optimum conditions having been provided. The experiment was conducted in the summer of 1950, involving soil fumigation and levels of ammonium sulfate. These variables were arranged in a 3 x 3 factorial design with four replications.

Low, medium and high levels of nitrogen as ammonium sulfate were added to the soil. These levels correspond to 20, 40 and 60 mg., respectively, of nitrogen per 100 grams of soil.

Two soil fumigants were used, D-D[1] and Dowfume W-40[2]; a third treatment involving no fumigation was included as a control.

D-D is a mixture containing approximately two-thirds dichloropropene and one-third dichloropropane and a small portion of trichlorides with high boiling point. It is a brownish liquid, slightly oily, about one-fifth heavier than water, completely volatile, and non-inflammable. It has a pungent, sweetish and somewhat nauseating odor. It often causes inflammation of the skin after a few minutes of contact. In the presence of moisture it is corrosive to metals.

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[1] Trade name Shell Chemical Corp. (Dichloropropene-dichloropropane).

[2] Trade name Dow Chemical Co. (Ethylene dibromide).

Dowfume W-40 is a liquid mixture containing 41 percent by weight of the active ingredient ethylene dibromide. Materials containing this compound are sold commercially under various other trade names. Dowfume W-40 is insoluble, non-inflammable, non-corrosive, and volatile.

A composite soil sample was taken, using a soil tube, from Arredondo loamy sand located on the Experiment Station Farm. Fifty cores were taken at random from an area of about one-fourth of an acre. The cores were taken from the top 6 inches of soil and were air-dried, screened and thoroughly mixed. Four hundred grams each of this soil were placed in 400 ml. beakers. Replications and individual treatments were assigned to the beakers at random.

A representative soil sample was taken from the total mixed sample and three pH determinations were made. The mean pH value of the soil was 5.6. Two grams of calcium carbonate were added to each beaker to raise the pH to the range of 6.5 to 7.5, to provide excess calcium to the nitrifying organisms, and to serve as a base for neutralizing the acid formed from the oxidation of ammonium sulfate used in carrying out the test, thus maintaining optimum conditions for the nitrifying organisms as mentioned by Waksman (49, 50).

Three nitrate nitrogen determinations were also made, using the same representative soil sample. These determinations showed the soil to be low in nitrate nitrogen, the mean value of the three determinations being 8 p.p.m.

On August 7, 1950, the soil samples were treated according to the experimental design with D-D and Dowfume W-40 at the rate of 0.2 ml. per beaker. This rate is equivalent to approximately thirty gallons per acre, assuming two million pounds of soil per acre-6-inches. The treatment was accomplished by making a hole in the soil with a glass rod in the middle of each beaker, about 1.5 to 2.0 inches deep. Then 0.2 ml. of the material used was placed at the bottom of the hole with a pipette. The hole was immediately closed by the aid of the glass rod. Water was added to each beaker at the rate of 8 gms. of water per 100 gms. of soil and the weight of each beaker was recorded. Every two or three days each beaker was weighed and moisture was added until it reached the recorded weight.

The next day after adding the fumigants, the appropriate measured amounts of ammonium sulfate were added to all treatments. All beakers were incubated at room temperature, ranging between 82° and 88°F. Precautions were taken to prevent any contamination from one beaker to the other. The following week a representative sample of 50 gms. of soil was taken from each beaker and a nitrate nitrogen analysis was made. Nitrate nitrogen determinations were made by the phenoldisulfonic acid method of Harper (16). A photoelectric colorimeter, "Lumetron Model 402-E", was used in this determination. Nitrate nitrogen analyses were made at intervals of three weeks with soil samples taken from each beaker. The experiment was stopped at the end of 10 weeks. All results were calculated as parts per million nitrate nitrogen in soil. All data were subjected to statistical analysis.

The second experiment in this phase of the work was designed to study the effect of D-D and Dowfume W-40 at several different rates of application on the nitrifying power of the soil under field conditions. The experiment was designed as a 3 x 3 factorial consisting of D-D, Dowfume W-40 and check treatments, with three rates of each fumigant. These rates were 1, 2.5 and 4 ml. of material per square foot of land. The 3 x 3 factorial was replicated 4 times. Each treatment occupied a plot 3 x 5 feet. Treatments within each replication were 3 feet apart and replications were 5 feet apart. Plots were cleaned free of weeds and plant residue and the top 3 inches were scraped and thoroughly pulverized prior to treatment. A pH determination was made for each plot and no appreciable differences in pH value were found, the mean value being 6.0. The initial nitrate nitrogen content of the soil was determined for each plot. Each individual treatment occupying 15 square feet received 150 grams of ammonium sulfate fertilizer. This amounts approximately to 100 p.p.m. nitrogen in the soil calculated on the basis of two million pounds per acre-6-inches. Ammonium sulfate was broadcast over the plots and mixed into the surface three inches of soil.

Each plot was divided into 15 parts of one square foot each. Fumigants were applied by a hand fumigation injector in the center of each square foot. The fumigation injector was calibrated to deliver the assigned level to each treatment. Injections were made 6 inches deep and the holes were immediately closed by pressing dirt into them with the foot.

A soil thermograph was placed in the middle of the plots and a record of soil temperature at a 6-inch depth for a period of 10 weeks was obtained.

Two weeks after applying the fumigants to the soil a sample from each individual treatment was taken. Three cores were taken at random from each individual treatment. A nitrate nitrogen analysis was made on these samples and the results were recorded as p.p.m. nitrate nitrogen in the soil. Soil samples were taken and nitrate nitrogen determinations were made every two weeks for a 10 week period. The five nitrate analyses which were made 2, 4, 6, 8 and 10 weeks after soil treatment were combined in one statistical analysis in order to obtain more information.

Results and Discussion

In the first experiment an attempt was made to study the effect of D-D and Dowfume W-40 on the nitrifying organisms in the soil. Results of the first nitrate analysis, which was made one week after applying these fumigants to the soil, showed that significant differences in nitrate nitrogen in the soil were found between treated and untreated soil. Table 1 shows the effect of soil fumigation treatment and three levels of nitrogen as ammonium sulfate added to the soil on the nitrifying soil organisms. Soil treated with D-D and Dowfume W-40 contained significantly lower nitrate nitrogen than untreated soil. Comparing D-D with Dowfume W-40, it was found that D-D gave significantly lower nitrate nitrogen levels than the Dowfume W-40. The varying levels of nitrogen as ammonium sulfate added to the soil did not show any differences in the first analysis. Results obtained from the first analysis are represented graphically in Fig. 1.

The second nitrate analysis, which was made four weeks after fumigation, showed significant differences in the nitrate nitrogen content of treated and untreated soil. Table 2 shows the effect of soil treatment and three levels of nitrogen as ammonium sulfate on the nitrate nitrogen content of the soil. D-D treated soil contained significantly less nitrate nitrogen than the Dowfume W-40 treated soil or untreated soil. Dowfume W-40 treatment was lower in nitrate

TABLE 1

Effect of Soil Fumigation and Levels of Ammonium Sulfate on the Average Nitrate Nitrogen Found in Soil One Week After Treatment

Mg. Nitrogen as Ammonium Sulfate Added to 100 gm. Soil	Soil Treatment Check	Dowfume W-40	D-D	Average for Ammonium Sulfate Level
	ppm.	ppm.	ppm.	ppm.
20	72.0	59.5	38.5	56.6
40	70.0	55.6	40.3	55.3
60	82.4	54.9	40.7	59.3
Average for Soil Treatments	74.8	56.6	39.8	

L.S.D. for averages for soil treatment and levels of ammonium sulfate at: 5% level = 6.4

1% level = 8.7

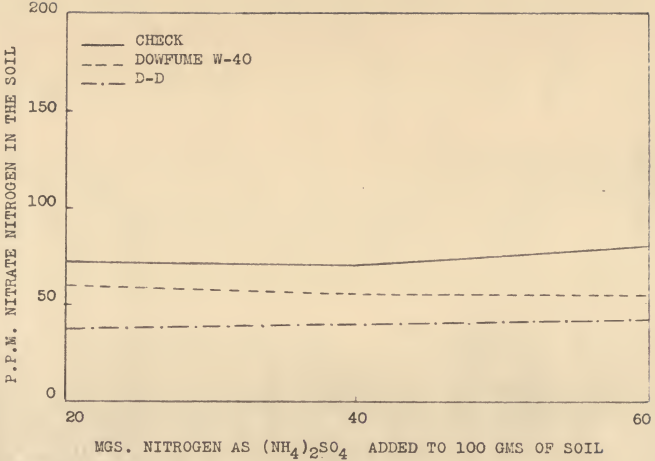

Fig.1. Effect of soil treatment on the nitrifying power of the soil one week after treatment.

TABLE 2

Effect of Soil Fumigation and Levels of Ammonium Sulfate on the Average Nitrate Nitrogen Found in Soil Four Weeks After Treatment

Mg. Nitrogen as Ammonium Sulfate Added to 100 gm. Soil	Soil Treatment			Average for Ammonium Sulfate Level
	Check	Dowfume W-40	D-D	
	ppm.	ppm.	ppm	ppm.
20	91.9	103.9	32.7	76.2
40	127.3	120.4	44.0	97.2
60	153.4	133.0	66.6	117.7
Average for Soil Treatments	124.2	119.0	47.8	

L.S.D. for averages for soil treatment and levels of ammonium sulfate at: 5% level = 14.7

1% level = 19.9

nitrogen content than the check; however, the difference was not statistically significant. Table 2 shows also that the three levels of ammonium sulfate added to the soil affected the amount of nitrate nitrogen formed in the soil. Treatments that received 60 mg. of nitrogen as ammonium sulfate contained significantly more nitrate nitrogen than treatments supplied with 40 mg. of nitrogen as ammonium sulfate. The latter were significantly higher in nitrate nitrogen content than treatments which received only 20 mg. of nitrogen as ammonium sulfate. Furthermore, statistical analysis showed that the three levels of ammonium sulfate added to the soil affected the nitrate nitrogen content in a linear fashion. This linear behavior of the levels of ammonium sulfate with the nitrate nitrogen found in the soil was highly significant. Results of the second nitrate analyses are represented graphically in Fig. 2.

Results of the third nitrate analysis, which was made seven weeks after soil treatment, showed significant differences between soil treatments. Nitrate nitrogen in p.p.m. of soil under different treatments and supplied with three levels of ammonium sulfate are presented in Table 3. Statistical analysis showed that D-D treated soil was still significantly lower in nitrate nitrogen content than either the Dowfume W-40 or the check treatments. The Dowfume W-40 treatment was lower in nitrate nitrogen content than the

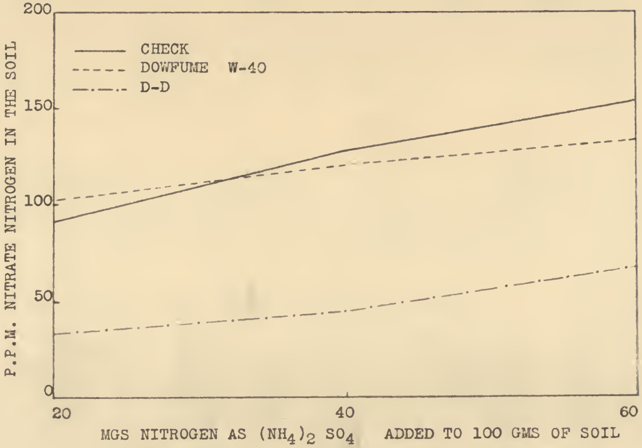

Fig.2. Effect of soil treatment on the nitrifying power of the soil four weeks after treatment.

TABLE 3

Effect of Soil Fumigation and Levels of Ammonium Sulfate on the Average Nitrate Nitrogen Found in Soil Seven Weeks After Treatment

Mg. Nitrogen as Ammonium Sulfate Added to 100 gm. Soil	Soil Treatment			Average for Ammonium Sulfate Level
	Check	Dowfume W-40	D-D	
	ppm.	ppm.	ppm.	ppm.
20	72.7	80.6	47.2	66.8
40	101.3	92.6	46.4	80.1
60	138.0	119.9	64.6	107.5
Average for Soil Treatments	104.0	97.7	52.7	

L.S.D. for averages for soil treatment and levels of ammonium sulfate at: 5% level = 11.1

1% level = 15.1

check treatment, but again, this difference was not significant. The levels of ammonium sulfate added to the soil affected the nitrate nitrogen content in the soil significantly. From Table 3 it is noticed that high significance exists between the high and low level as well as medium and high level but between medium and low levels the difference was significant only at 5 per cent level. Fig. 3 is a graphical representation of nitrate nitrogen content in different soil treatments when supplied with different levels of ammonium sulfate. Statistical analysis shows, furthermore, that the increase of nitrate nitrogen content of the soil due to increasing the level of ammonium sulfate added to the soil behaves in a linear fashion.

Ten weeks after treatment nitrate nitrogen in the soil still differed significantly. Table 4 shows results of the fourth nitrate analysis which was made 10 weeks after soil treatment. Nitrate nitrogen content of the D-D treated soil was relatively high; however, it was significantly lower than either the Dowfume W-40 or check treatment. There was no significant difference in nitrate nitrogen content of Dowfume W-40 and check treatments. The levels of ammonium sulfate added to the soil affected the nitrate content of the soil significantly. Soil supplied with the high level of ammonium sulfate contained significantly higher amounts of nitrate nitrogen than soil which received the medium level. The latter was significantly higher in nitrate nitrogen

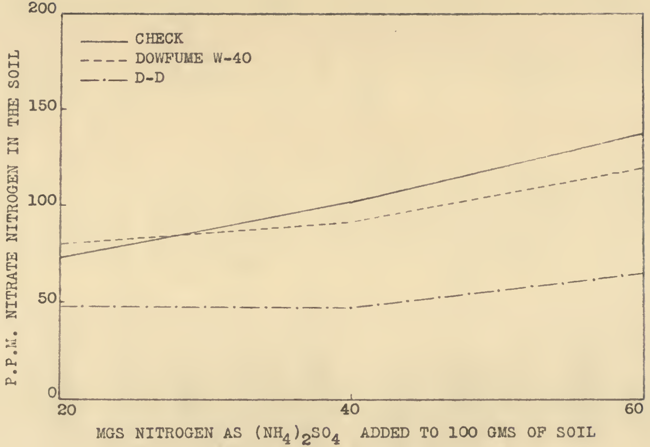

Fig.3. Effect of soil treatment on the nitrifying power of the soil seven weeks after treatment

TABLE 4

Effect of Soil Fumigation and Levels of Ammonium Sulfate on the Average Nitrate Nitrogen Found in Soil Ten Weeks After Treatment

Mg. Nitrogen as Ammonium Sulfate Added to 100 gm. Soil	Soil Treatment			Average for Ammonium Sulfate Level
	Check	Dowfume W-40	D-D	
	ppm.	ppm.	ppm.	ppm.
20	110.8	112.2	95.0	106.0
40	157.5	150.0	124.0	143.8
60	199.0	172.7	127.2	166.3
Average for Soil Treatment	155.7	144.9	115.4	

L.S.D. for averages for soil treatment and levels of ammonium sulfate at: 5% level = 14.4

1% level = 19.5

content than soils supplied with the lowest level. Results of the fourth nitrate analysis are represented graphically in Fig. 4. The effect of the levels of ammonium sulfate added to the soil on the amounts of nitrate nitrogen in the soil was found to behave in a linear fashion. The four nitrate analyses 1, 4, 7 and 10 weeks after soil treatment are represented graphically in Fig. 5.

Results obtained from experiments conducted to test the effect of soil fumigation on soil nitrification under field conditions agree to a great extent with results obtained in the first experiment made under controlled conditions. The main difference was shown in the first nitrate analysis in the experiment conducted under field conditions with no significant difference obtained between treated and untreated soil. The effect of soil treatment over a period of 10 weeks on soil nitrification is presented in Table 5. This table shows that there is no significant difference in nitrate nitrogen content of the treated and untreated soil in the first nitrate analysis which was made 2 weeks after fumigation (L. S. D. for individuals). One possible explanation is the low soil temperature that occurred during the first two weeks after treatment. The soil thermograph placed in the middle of the plots recorded maximum soil temperature during the first two weeks of approximately 60°F. The minimum temperature recorded during this period was about 40°F. Low soil temperature was probably the limiting factor

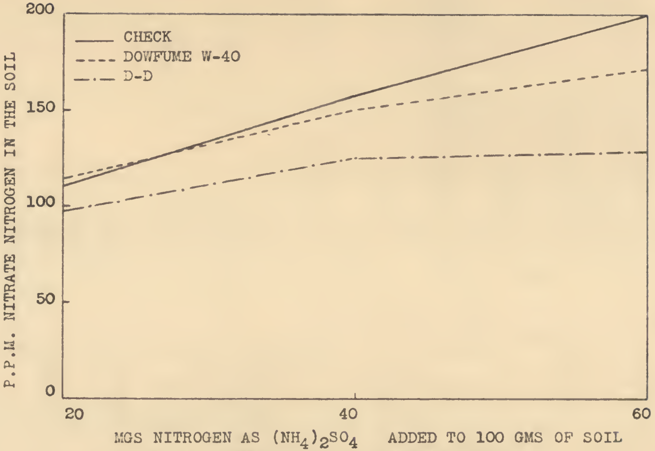

Fig.4. Effect of soil treatment on the nitrifying power of the soil ten weeks after treatment.

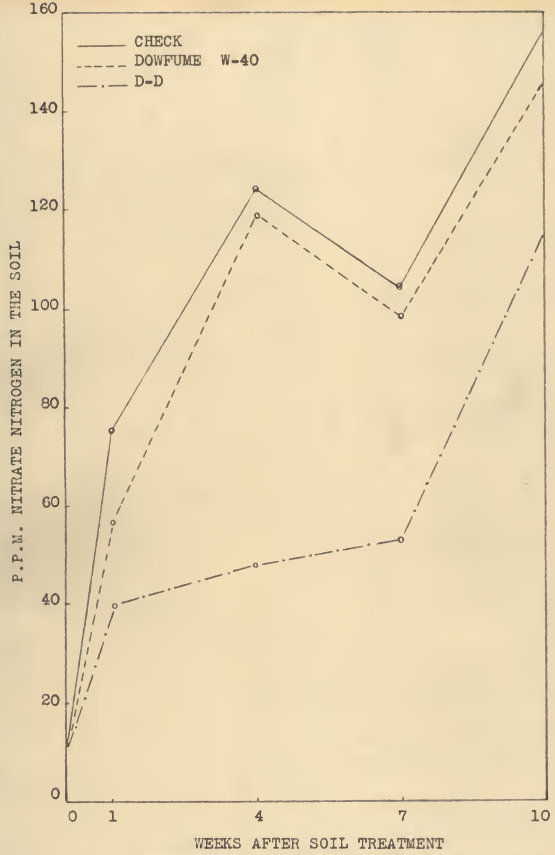

Fig.5. Effect of soil treatment on the nitrifying power of the soil under controlled conditions

TABLE 5

Effect of Soil Fumigation on the Average Nitrate Nitrogen Found in the Soil Over Ten Weeks Period Under Field Conditions

Dates Weeks After Treatment	Soil Treatment			Average for Dates
	Check	Dowfume W-40	D-D	
	ppm. NO_3N	ppm.	ppm.	
2	8.9	7.0	6.8	7.6
4	19.0	12.8	8.6	13.5
6	26.7	19.4	10.7	18.9
8	55.3	32.6	12.9	33.6
10	65.7	35.9	11.6	37.7
Averages for Soil Treatment	35.1	21.5	10.1	

L.S.D. for average soil treatment at:

5% level = 3.8

1% level = 5.1

L.S.D. for average weeks after treatment at:

5% level = 3.1

1% level = 4.1

L.S.D. for individuals at:

5% level = 5.3

1% level = 7.1

for soil nitrification and no difference in nitrate nitrogen content was found between treated and untreated soil. Nitrate nitrogen content of the soil was greatly reduced on the average of 10 weeks in the treated plots. D-D treated soil contained significantly lower nitrate nitrogen than Dowfume W-40 treatments during all the time of experiment. This indicates that D-D has a more destructive effect on the nitrification organisms of the soil than Dowfume W-40. Table 5 also shows the significant increase in nitrate nitrogen content of the soil 2, 4, 6, 8 and 10 weeks after treatment. Statistical analysis showed that this increase followed linear regression.

The three levels of soil fumigants, 1, 2½ and 4 ml. per square foot added to the soil, did not differ greatly in their effect on the nitrification power of the soil. However, significant effect of these levels was obtained with D-D treatments in the fifth nitrate analysis, which was made 10 weeks after soil treatments. Table 6 shows that plots treated with D-D at the rate of 4 ml. per square foot were significantly lower in nitrate nitrogen content at this time than those receiving 1 and 2½ ml. of fumigant material per square foot. Results of the nitrification experiment under field conditions over the period of 10 weeks are represented graphically in Fig. 6.

The inhibiting effect of soil fumigants on the nitrifying organisms of the soil has been studied and reported by

TABLE 6

Effect of D-D Levels on the Average Nitrate Nitrogen in the Soil Ten Weeks After Treatment

Replications	Levels of D-D (ml./ft.^{2})		
	1.00	2.5	4.0
	ppm.	ppm.	ppm.
1	20.0	15.5	7.4
2	15.0	11.8	5.7
3	11.8	11.8	6.4
4	15.0	12.0	6.4
Average for Levels	15.4	12.8	6.5

L.S.D. for averages for levels of D-D

at: 5% level = 4.9

1% level = 5.9

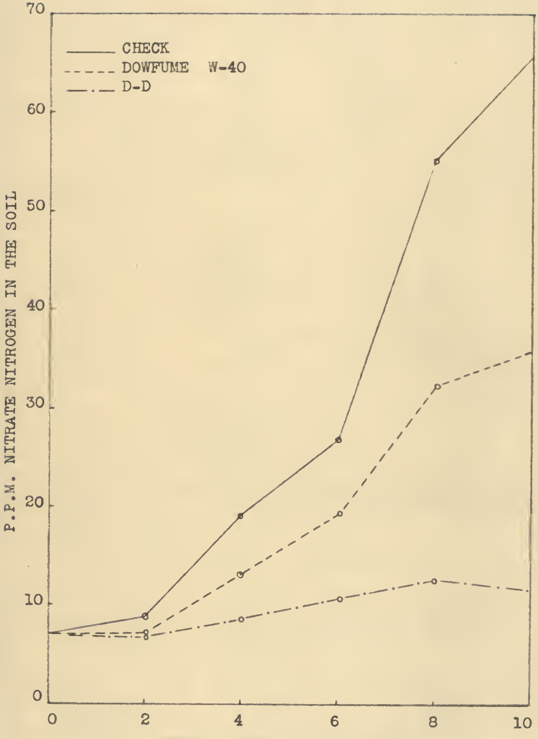

Fig.6. Effect of soil treatment on the nitrifying power of the soil under field conditions.

other investigators working with similar fumigation materials.

Spencer and Jack (41) studied the effect of chloropicrin, ethylene dibromide and methyl bromide as soil fumigants on nitrogen transformation in seedbeds. They found that all fumigated plots were higher in ammoniacal nitrogen than were the check plots. This difference held for 70 days, but it was statistically significant for only the first 42 days following the treatment. The nitrate data show the reverse to be true. The nitrate nitrogen content of the check plots was higher than that of the fumigated plots. This difference was statistically significant with both chloropicrin and methyl bromide.

Volk (48) stated that D-D was more effective in promoting persistence of ammonia in the soil following fertilization than Dowfume W-40, and the latter was significantly above the check.

PART II. Effect of Soil Fumigation on Tomato Plant Behavior

Materials and Methods

Results obtained from Part I "Effect of Soil Fumigation on Soil Nitrification" showed that ammonium sulfate was slow in its conversion to nitrates in fumigated soil. Therefore, it was desirable to ascertain whether or not ammonium sulfate as a sole source of nitrogen had any effect on the early growth of tomato plants. It was with this purpose in mind that the following tests were made.

The first experiment was conducted to study the effect of soil treatment on the behavior of tomato plants when supplied with two sources of nitrogen, two levels of potassium and two levels of magnesium. Potassium and magnesium were included in this experiment because of their relationship in nitrogen assimilation in tomato plants.

The experiment was designed as a 2 x 2 x 2 factorial within a split plot. Each block was split into three main plots, including D-D, Dowfume W-40 and check treatment. Two sources of nitrogen, two levels of potassium and two levels of magnesium were investigated factorially within each plot. Each block was replicated three times.

The experiment was conducted on the greenhouse bench in 8-inch pots. Soil used was Arredondo loamy sand taken from the Experiment Station farm. The soil was dried, screened and thoroughly mixed. Each individual treatment was represented by one pot filled with 10 pounds of soil.

The soil fumigation was done by making a hole 3 to 4 inches deep in the soil at the center of each pot and placing 2 ml. of the fumigant material in the bottom of each hole with a pipette. The holes were immediately closed and small amounts of water were added to each pot to serve as a water seal.

The day following fumigation the fertilizer materials were added to each pot according to the experimental design. All fertilizer materials were added to the soil on the basis of parts of element per million parts of soil. The two sources of nitrogen used were ammonium sulfate and sodium nitrate. They were added to the soil in dilute water solutions at the rate of 200 p.p.m. as nitrogen to the soil. Potassium in the form of potassium chloride in water solution was applied at two levels, 10 and 50 p.p.m. potassium. Magnesium was added to the soil in the form of magnesium oxide in two levels, 5 and 25 p.p.m. magnesium. Each pot received 1 gram of mono-calcium phosphate. To receive any excess leaching of fertilizer, a petridish was placed under each pot.

One week after soil treatment, 40-day old tomato plants of the Rutgers variety were transplanted to the pots, one plant to each pot. An effort was made to choose plants of the same size. All pots were watered after transplanting and whenever plants needed it later, with equal amounts of water. Leachate found in the petri dish placed under the pot was returned to the surface of the soil.

One week after transplanting it was noticed that plants grown in fumigated pots were pale in color and growing slowly. Photographs of plants growing in different soil treatments were taken at that time.

The slow growth of the plants in fumigated pots was probably due to the excess fumigants remaining in the soil. An attempt was made to help remove these excess fumigants from the soil by making 3 holes 4 inches in depth in the soil of each pot. One week after making these holes the plants in fumigated pots began to recover and new growth started.

At the end of the fourth week after transplanting leaf samples were taken from each plant. Young growing leaves in the top of each plant were sampled. Leaf samples were dried in a forced-draft oven at 60°C. for about 8 hours and ground to pass a 60-mesh screen.

Chemical analysis for total nitrogen, potassium, calcium, and magnesium were made on the leaf samples. Total nitrogen was determined by micro-modification of the Ranker (35) method. When nitrates were present, 20-30 mgs. of dried tissue were placed in a micro-digestion flask, 2 ml. of sulfuric-salicylic acid mixture (40 gm. of salicylic acid per liter of concentrated sulfuric acid) was added. A few crystals of potassium sulfate and copper sulfate and about

0.1 gm. of sodium thiosulfate were then added. The flasks were heated with a small flame of a microburner in order to avoid excessive frothing. The flame was gradually increased and finally turned on full. A complete digestion usually took from two to three hours. A micro-distillation apparatus was used and the ammonia was trapped in 2 per cent boric acid and titrated with HCl of known normality using a mixed indicator (Methylene Blue 0.0826 gm. and Methyl Red, 0.125 gm.) in 100 ml. ethyl alcohol. Potassium and calcium were determined by the flame photometer, as described by Sharpe and Gammon (37) and Perkins (34). The thiazol yellow method proposed by Drosdoff and Nearpass (9) was used for magnesium determination. All results were reported as percentage of element on a dry-weight basis. The data were subjected to statistical analysis.

At the end of the experiment the roots of plants were pulled out of the soil carefully, examined and photographed.

The first experiment was repeated and tomato plants were transplanted two weeks after fumigation and leaf samples were taken eight weeks after transplanting.

Results and Discussion

In the first experiment, when tomato plants were transplanted in pots one week after soil treatment, differences in the growth of the plants in the different soil treatments were noted. Plate II shows three tomato plants grown under the three different soil treatments. Tomato plants grown in D-D fumigated soil were smaller in size than those grown in unfumigated soil. The Dowfume W-40 treatment produced plants intermediate in size between D-D treatment and untreated soil.

At the completion of leaf sampling each plant was removed from the individual pots, soil shaken from the roots and the root system was observed. Plate III shows the roots of three plants which were fumigated with D-D. A part of each main root was barren of secondary roots. The effect of Dowfume W-40 treatment on the roots of plants was less pronounced than D-D treatment. Plate IV shows the roots of three plants which were grown in soil fumigated with Dowfume W-40. The roots of the plants grown in soil which had received no fumigation treatment appeared to be normal and vigorous with an even distribution of secondary roots. In Plate V the typical root system obtained from the check treatments is seen for comparison with those grown after the two different fumigants.

Statistical analysis for total nitrogen determination

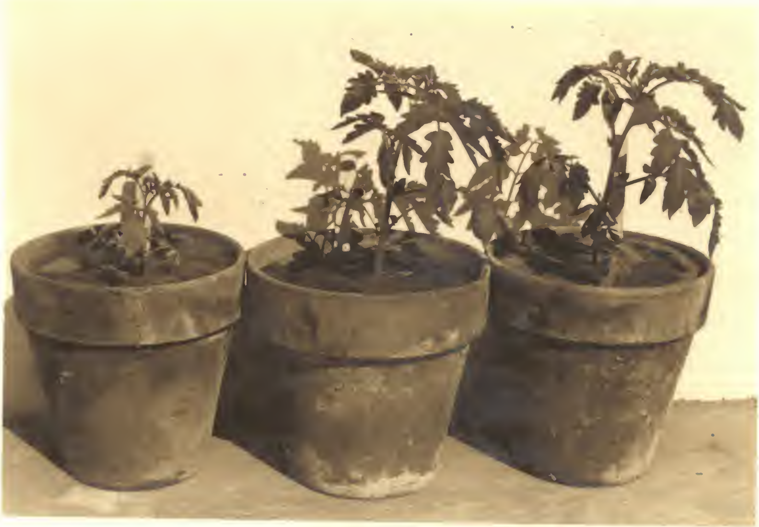

PLATE II. Effect of Soil Treatment on the Growth of Tomato Plants Transplanted One Week After Soil Treatment. Left to Right - D-D, Dowfume W-40 and Check.

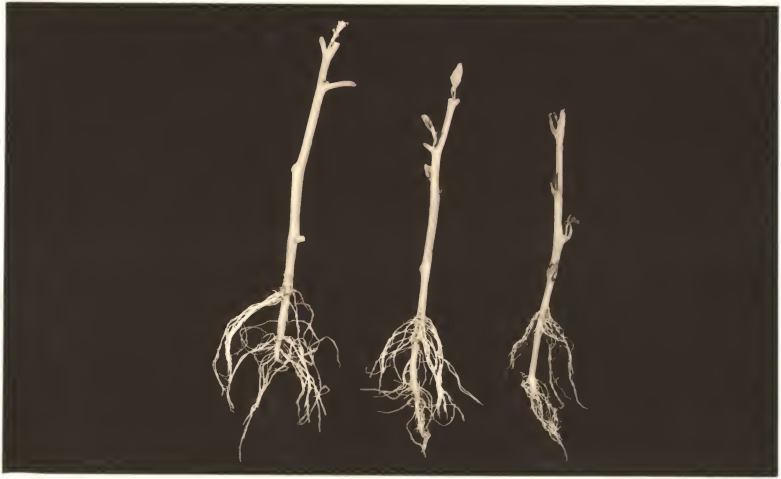

PLATE III. Effect of Soil Fumigation on the Roots of Three Tomato Plants Transplanted One Week After Soil Treatment with D-D.

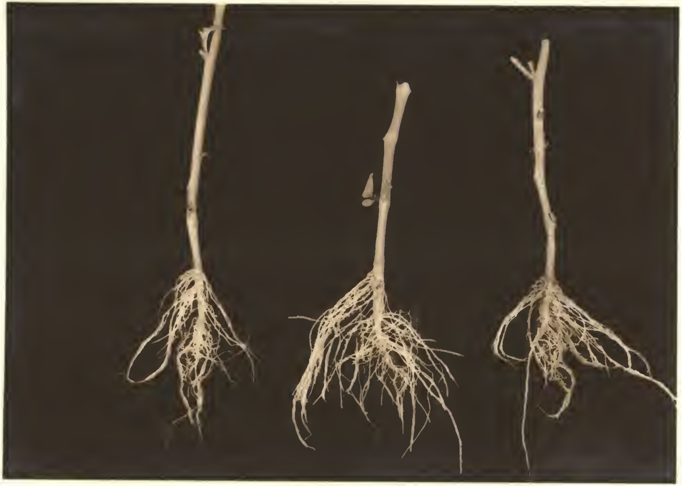

PLATE IV. Effect of Soil Fumigation on the Roots of Three Tomato Plants Transplanted One Week After Soil Treatment with Dowfume W-40.

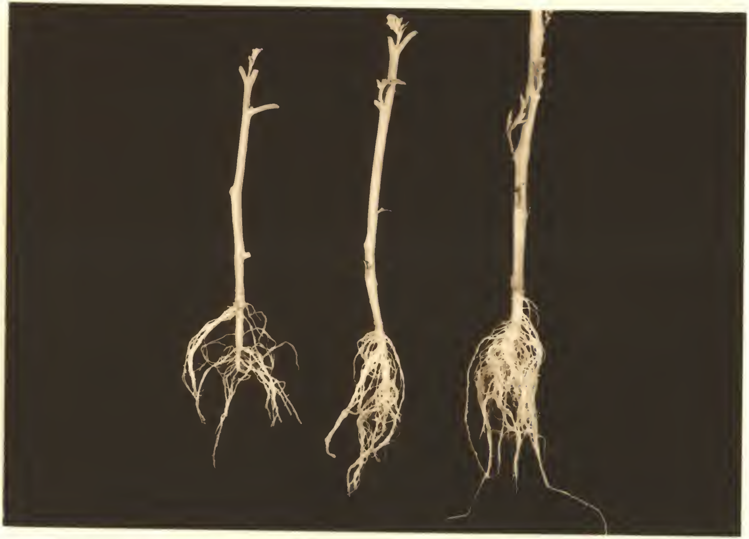

PLATE V. Effect of Soil Fumigation on the Roots of Tomato Plants Transplanted One Week after Soil Treatment. Left to Right - D-D, Dowfume W-40 and No Treatment.

of tomato leaves shows that the average per cent total nitrogen of plants from the D-D and Dowfume W-40 treatments was significantly higher than in the plants grown in unfumigated soil. Comparing D-D treated plants with unfumigated plants the difference was highly significant. The effect of soil treatment and source of nitrogen on the average per cent total nitrogen in tomato leaves is shown in Table 7. Data in this table show that the source of nitrogen spplied to the soil had a highly significant influence on the percentage total nitrogen in plants. Ammoniacal nitrogen fertilized plants contained a significantly higher percentage of total nitrogen than those supplied with nitrate nitrogen. Clark (6) studied the effect of ammonium and of nitrate nitrogen on the composition of tomato plants. He found that tomato plants of the Marglobe variety supplied with ammoniacal nitrogen contained a higher percentage of total nitrogen in the leaves than those receiving the same amount of nitrogen in nitrate form. He further stated that this was due to a much greater concentration of insoluble or protein nitrogen as well as of soluble organic nitrogen in ammonium fertilized plants.

The potassium content of the tomato leaves was found to be affected by the soil treatment. Table 8 shows the effect of soil treatment and the two sources of nitrogen on the average percentage of potassium in tomato leaves.

TABLE 7

Effect of Soil Fumigation and Different Sources of Nitrogen on the Per Cent Total Nitrogen in Leaves of Four Week Old Tomato Plants

Soil Fumigation	Sources of Nitrogen		Average for Soil Fumigation
	Ammoniacal N	Nitrate N	
Check	5.70	3.48	4.59
Dowfume W-40	5.84	3.81	4.82
D-D	6.08	3.93	5.00
Average for Sources of Nitrogen	5.87	3.74	

L.S.D. for soil fumigation averages

at: 5% level = .23

1% level = .38

L.S.D. for source of nitrogen averages

at: 5% level = .25

1% level = .34

TABLE 8

Effect of Soil Fumigation and Different Sources of Nitrogen on the Percentage of Potassium in Leaves of Four Week Old Tomato Plants

Soil Fumigation	Sources of Nitrogen		Average for Soil Fumigation
	Ammoniacal N	Nitrate N	
Check	2.93	2.59	2.76
Dowfume W-40	3.46	2.82	3.14
D-D	3.43	2.95	3.19
Average for Sources of Nitrogen	3.27	2.79	

L.S.D. for soil fumigation averages

at: 5% level = .13

1% level = .22

L.S.D. for source of nitrogen averages

at: 5% level = .17

1% level = .23

Plants grown in fumigated soil contained a significantly higher percentage of potassium than those grown in soil not fumigated. There was no significant difference in the potassium content between the plants in the D-D fumigated soil and those in the Dowfume W-40 treated soil. The source of nitrogen, also, showed a significant influence on the potassium content of the leaves. Ammoniacal nitrogen fertilized plants contained a significantly higher percentage of potassium than those supplied with nitrate nitrogen. The two levels of potassium applied to the soil were found to have a significant effect on the potassium content of the leaves as shown in Table 9. Plants supplied with a high level of potassium contained a significantly higher percentage of potassium in their leaves than those grown with a low level of potassium. The interaction between the soil treatment and the fertilizer materials added to the soil was found to have an insignificant effect on the potassium content of the leaves.

The effect of soil treatment and the two sources of nitrogen on the magnesium content of tomato leaves are presented in Table 10. There were no significant differences in the magnesium content of tomato leaves under the three different soil treatments. However, by testing the effect of nitrogen sources on the magnesium content of the leaves it was found that nitrate nitrogen fertilized plants contained

TABLE 9

Effect of Potassium Levels and Two Sources of Nitrogen on the Per Cent Potassium in Leaves of Four Week Old Tomato Plants

Levels of Potassium	Sources of Nitrogen		Average for Sources of Nitrogen
	Ammoniacal N	Nitrate N	
10 ppm. Potassium in soil	3.08	2.72	2.90
50 ppm. Potassium in soil	3.46	2.85	3.16
Average for Levels of Potassium	3.27	2.79	

L.S.D. for source of nitrogen and level of potassium averages

at: 5% level = .17

1% level = .23

TABLE 10

Effect of Soil Fumigation and Different Sources of Nitrogen on the Percentage of Magnesium in Leaves of Four Week Old Tomato Plants

Soil Fumigation	Sources of Nitrogen		Average for Soil Fumigation
	Ammoniacal N	Nitrate N	
Check	.39	.44	.41
Dowfume W-40	.43	.48	.45
D-D	.39	.46	.42
Average for Sources of Nitrogen	.40	.46	

L.S.D. for soil fumigation averages

at: 5% level = .06 N.S.

L.S.D. for source of nitrogen averages

at: 5% level = .04

1% level = .05

a significantly higher percentage of magnesium than plants supplied with ammoniacal nitrogen.

Chemical analysis for the calcium content of tomato leaves showed that the soil fumigation treatments tested had no effect on the calcium content of the leaves. Table 11 shows the effect of soil treatment and the two sources of nitrogen on the calcium content of leaves of four-week old tomato plants. This table shows that the source of nitrogen has a significant effect on the calcium percentage of the leaves. Plants receiving ammoniacal nitrogen contained significantly less calcium than those supplied with nitrate nitrogen. Although soil treatment had no effect on the calcium content of the leaves, the interaction between soil treatment and source of nitrogen was statistically significant. Tomato plants grown under the three different soil treatments did not respond alike in their calcium content with the two sources of nitrogen applied to the soil. These results are represented graphically in Fig. 7. There was no significant difference in the calcium content of leaves in ammonia fertilized plants under the three soil treatments; however, the difference in calcium content of the leaves in nitrate supplied plants was significant under the three soil treatments. Nitrate nitrogen fertilized plants grown in D-D fumigated soil contained a significantly higher percentage of calcium than those receiving nitrate nitrogen but unfumigated.

TABLE 11

Effect of Soil Fumigation and Different Sources of Nitrogen on the Percentage of Calcium in Leaves of Four Week Old Tomato Plants

Soil Fumigation	Sources of Nitrogen		Average for Soil Fumigation
	Ammoniacal N	Nitrate N	
Check	1.18	1.82	1.50
Dowfume W-40	0.94	1.95	1.42
D-D	0.93	2.13	1.53
Average for Sources of Nitrogen	1.02	1.97	

L.S.D. for soil fumigation averages

at: 5% level = 0.28 N.S.

L.S.D. for source of nitrogen averages

at: 5% level = 0.15

1% level = 0.20

L.S.D. for individuals

at: 5% level = 0.26

1% level = 0.35

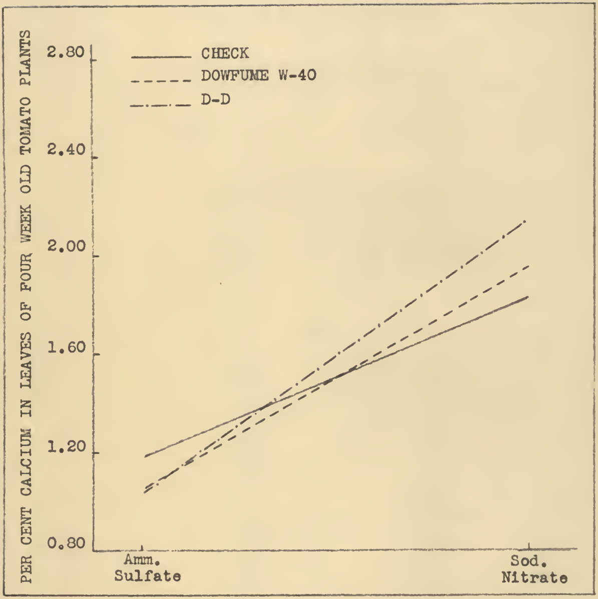

Fig.7. Effect of soil fumigation and source of nitrogen on the average per cent calcium in leaves of four week old tomato plants.

The effect of the two sources of nitrogen on the total nitrogen, potassium, calcium and magnesium content of leaves of four-week-old tomato plants is represented graphically in Fig. 8.

Table 12 shows the analysis of variance for total nitrogen, potassium, magnesium and calcium percentage in leaves of four-week-old tomato plants.

The effect of soil fumigation on the per cent total nitrogen, potassium, calcium and magnesium in leaves of four-week-old tomato plants is represented graphically in Fig. 9.

Soil treatment affected the total nitrogen percentage of tomato leaves in the second experiment when tomato plants were transplanted two weeks after soil fumigation treatment and leaf samples were taken 8 weeks after transplanting. Table 13 shows the effect of soil treatment and the two sources of nitrogen applied to the soil on the percentage total nitrogen in tomato leaves. Plants grown in D-D fumigated soil contained significantly higher percentages of nitrogen than the Dowfume W-40 and check treatments. However, there was no significant difference in nitrogen content of the leaves of plants grown in soil fumigated with Dowfume W-40 and in unfumigated soil. Data in Table 13 show also that the percent total nitrogen of leaves was affected by the two sources of nitrogen added to the soil. Ammoniacal

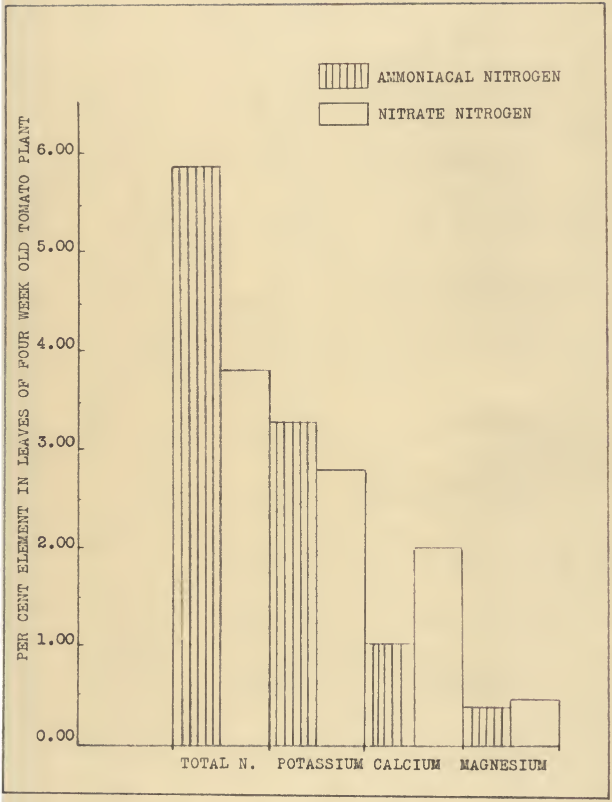

Fig.8. Effect of the different sources of nitrogen on the percentage total nitrogen, potassium, calcium and magnesium in leaves of four week old tomato plants.

TABLE 12

Analysis of Variance for the Percentage of Total Nitrogen, Potassium, Magnesium and Calcium in Leaves of Four Week Old Tomato Plants

		Sum Squares			
Source of Variation	D.F.	Nitrogen Analysis	Potassium Analysis	Magnesium Analysis	Calcium Analysis
Grand Total	71	100.4377	15.5631	0.5160	23.4450
Main Treatment	8	3.3443	2.7593	0.1010	0.6832
Soil Treatment	2	2.0772*	2.6439**	0.0255	0.0932
Replication	2	.9431	.0079	0.0529	0.1014
Error "A"	4	.3240	.1075	0.0226	0.4386
Fertilization	7	82.9359	6.1422	0.0835	17.0704
Source of N.	1	81.7077**	4.2389**	0.0612**	16.3687**
Level of K	1	.0642	1.1884	0.0035	0.0010
Level of Mg.	1	.0396	.0260	0.0000	0.1891
Source N. x Levels K.	1	.0008	.2775	0.0000	0.0052
Source N. x Levels Mg.	1	.5995	.0767	0.0004	0.2123
Levels K. x Levels Mg.	1	.2123	.1596	0.0168	0.2580
K. x Mg. x Source N.	1	.2485	.1750	0.0014	0.0360
Soil Fum. x Fert.	14	2.2884	1.2439	0.0520	1.5590
Soil Fum. x Source N	2	1.1076	.2874	0.0013	1.0001*
Soil Fum. x K	2	0.0248	.2503	0.0190	0.0811
Soil Fum. x Mg.	2	1.0020	.0514	0.0100	0.2741
Residuals	8	.1540	.6548	0.0270	0.2037
Error "B"	42	11.8691	5.4177	0.2795	4.1324

*Significant at 5% level.

**Significant at 1% level.

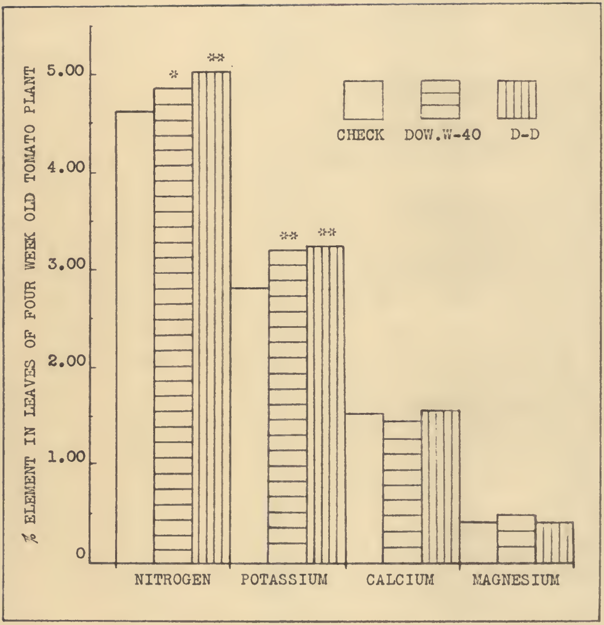

Fig.9. Effect of soil fumigation on the average per cent nitrogen, potassium, calcium and magnesium in leaves of four week old tomato plants.

* Significance at 5% level over the check.

** Significance at 1% level over the check.

TABLE 13

Effect of Soil Fumigation and Sources of Nitrogen on the Per Cent Total Nitrogen in Leaves of Eight Week Old Tomato Plants

Soil Fumigation	Sources of Nitrogen		Average for Soil Fumigation
	Ammoniacal N	Nitrate N	
Check	2.85	2.24	2.54
Dowfume W-40	3.05	2.14	2.59
D-D	3.49	2.29	2.89
Average for Sources of Nitrogen	3.13	2.22	

L.S.D. for average sources

at: 5% level = .19

1% level = .25

L.S.D. for soil fumigation averages

at: 5% level = .29

1% level = .48

L.S.D. for individuals

at: 5% level = .32

1% level = .43

nitrogen fertilized plants were significantly higher in per cent total nitrogen than those supplied with nitrate nitrogen. The interaction between soil treatments and the two sources of nitrogen was found to be statistically significant. This interaction is represented graphically in Fig.10. Plants under the three different soil treatments responded differently to the two sources of nitrogen. Ammoniacal nitrogen fertilized plants differed significantly in their total nitrogen percentage when grown in the different soil treatments. However, plants supplied with nitrate nitrogen did not show any significant difference in their total nitrogen percentage under the different soil treatments.

The chemical analysis for the potassium content in tomato leaves showed that plants grown in fumigated soil contained higher percentages of potassium than plants grown in unfumigated soil. However, these differences were not significant. Table 14 shows the effect of soil treatment and the two sources of nitrogen on the percentage of potassium in tomato leaves 8 weeks old. It is seen in this table that the potassium content of the leaves was markedly affected by the two sources of nitrogen applied to the soil. Plants supplied with nitrate nitrogen contained significantly lower percentages of potassium than plants fertilized with ammoniacal nitrogen. The potassium content of the tomato leaves was also affected by the two levels of potassium added to the

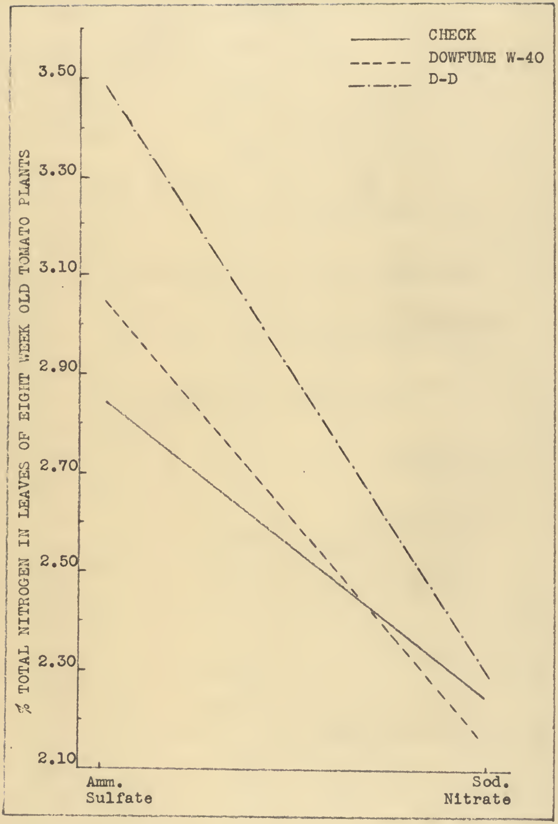

Fig.10. Effect of soil fumigation and sources of nitrogen on the average per cent total nitrogen in leaves of eight week old tomato plants.

TABLE 14

Effect of Soil Fumigation and Sources of Nitrogen on the Percentage Potassium in Leaves of Eight Week Old Tomato Plants

Soil Fumigation	Sources of Nitrogen		Averages for Soil Fumigation
	Ammoniacal N	Nitrate N	
Check	2.00	1.79	1.90
Dowfume W-40	2.25	2.09	2.17
D-D	2.62	2.13	2.38
Averages for Source of Nitrogen	2.29	2.01	

L.S.D. for soil fumigation averages

at: 5% level = .50 N.S.

L.S.D. for source of nitrogen averages

at: 5% level = .14

1% level = .18

soil as shown in Table 15. Tomato plants supplied with low potassium level were found to be significantly lower in potassium content than plants grown in the high level of potassium. Wall (51) studied the effect of varying amounts of potassium on the growth status and metabolism of tomato plants. He found that plants grown at a high level of potassium contained a higher percentage of potassium in their leaves. It was found also that the two levels of potassium interacted with the two sources of nitrogen. Table 15 shows this interaction (L. S. D. for individuals). Plants grown in the high level of potassium contained significantly more potassium when supplied with ammoniacal nitrogen than those fertilized with nitrate nitrogen, but with the low level of potassium, there was no significant difference in potassium content of the leaves between ammoniacal and nitrate nitrogen. It was also found that the interaction between the soil treatment and the two levels of magnesium had a significant influence on the potassium content of the leaves. Table 16 shows the effect of soil treatment and the two levels of magnesium on the percentage of potassium in the leaves. Plants grown in untreated soil and supplied with the low level of magnesium contained higher percentages of potassium than those grown under the same soil treatment and supplied with the high level of magnesium. However, plants grown in soil with the Dowfume W-40 treatment and supplied with the

TABLE 15

Effect of Sources of Nitrogen and Two Levels of Potassium on the Percentage of Potassium in Leaves of Eight Week Old Tomato Plants

Levels of Potassium	Sources of Nitrogen		Average for Levels of Potassium
	Ammoniacal N	Nitrate N	
Low Level 10 ppm. K in Soil	1.98	1.86	1.92
High Level 50 ppm. K in Soil	2.60	2.15	2.38
Average for Sources of Nitrogen	2.29	2.01	

L.S.D. for source of Nitrogen and level of Potassium averages at: 5% level = .14

1% level = .18

L.S.D. for individuals at: 5% level = .19

1% level = .26

TABLE 16

Effect of Soil Fumigation and Two Levels of Magnesium Added to the Soil on the Percentage of Potassium in Leaves of Eight Week Old Tomato Plants

Soil Fumigation	Levels of Magnesium in Soil		Average For Soil Fumigation
	Low Magnesium 5 p.p.m. Mg.	High Magnesium 20 p.p.m.	
Check	2.02	1.78	1.90
Dowfume W-40	2.07	2.26	2.17
D-D	2.41	2.34	2.38
Averages for Level of Magnesium	2.17	2.13	

L.S.D. for soil fumigation averages

at: 5% level = .50 N.S.

L.S.D. for levels of magnesium averages

at: 5% level = .14 N.S.

L.S.D. for individuals

at: 5% level = .23

1% level = .31

low level of magnesium contained lower percentages of potassium than those supplied with the high level of magnesium. This interaction between the three different soil treatments and the two levels of magnesium is represented graphically in Fig. 11.

The chemical analysis for magnesium in tomato plant leaves showed that soil treatment affected the magnesium content of the leaves significantly. Table 17 shows the effect of soil treatment and the two sources of nitrogen on the magnesium content of tomato plant leaves. Plants grown in soil fumigated with D-D and Dowfume W-40 contained significantly higher percentages of magnesium than plants grown in unfumigated soil. The two sources of nitrogen applied to the soil did not show a significant influence on the magnesium content of the tomato leaves.

Soil treatment was found to have no significant effect on calcium content of tomato plant leaves. Table 18 shows the effect of soil treatment and the two sources of nitrogen on the calcium percentage in tomato leaves. The two sources of nitrogen added to the soil seem to have a highly significant effect on the calcium content of tomato leaves. Plants supplied with nitrate nitrogen were found to contain a significantly higher percentage of calcium than those receiving ammoniacal nitrogen. This table also shows a significant interaction between the soil treatment and the two

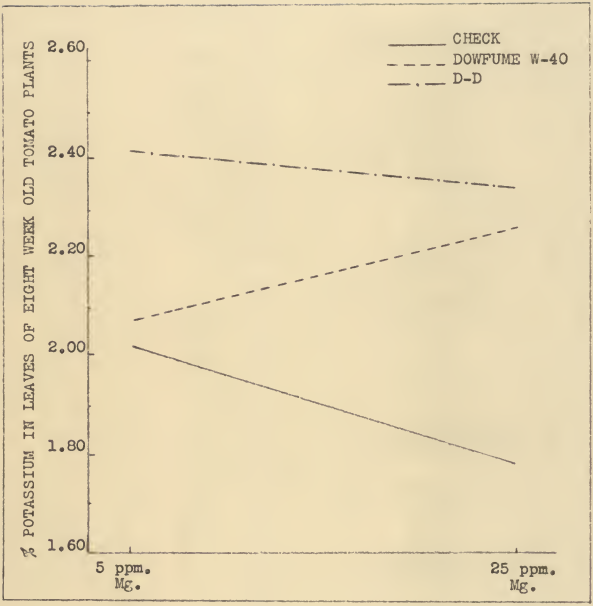

Fig.11. Effect of soil fumigation and levels of magnesium on the average per cent potassium in leaves of eight week old tomato plants.

TABLE 17

Effect of Soil Fumigation and Sources of Nitrogen on the Percentage of Magnesium in Leaves of Eight Week Old Tomato Plants

Soil Fumigation	Sources of Nitrogen		Average for Soil Fumigation
	Ammoniacal N	Nitrate N	
Check	.35	.33	.34
Dowfume W-40	.41	.38	.39
D-D	.39	.41	.40
Average for Sources of Nitrogen	.38	.37	

L.S.D for soil fumigation averages

at: 5% level = .04

1% level = .07

L.S.D. for source of nitrogen averages

at: 5% level = .03 N.S.

TABLE 18

Effect of Soil Fumigation and Sources of Nitrogen on the Percentage of Calcium in Leaves of Eight Week Old Tomato Plants

Soil Fumigation	Sources of Nitrogen		Averages for Soil Fumigation
	Ammoniacal N	Nitrate N	
Check	1.18	1.58	1.38
Dowfume W-40	1.32	1.61	1.46
D-D	1.15	1.70	1.43
Averages for Source of Nitrogen	1.22	1.63	

L.S.D. for soil fumigation averages

at: 5% level = .29 N.S.

L.S.D. for source of nitrogen averages

at: 5% level = .08

1% level = .11

L.S.D. for individuals

at: 5% level = .14

1% level = .19

sources of nitrogen. The calcium content of plants which were supplied with nitrate nitrogen was not significantly different under the three soil treatments. However, when plants were supplied with ammoniacal nitrogen it was found that there is significant difference in calcium content of tomato plant leaves under the three soil treatments. Dowfume W-40 treatments produced plants containing significantly higher percentages of calcium than D-D and check treatments only when supplied with ammoniacal nitrogen. This interaction between soil treatment and the two sources of nitrogen is represented graphically in Fig. 12. The two levels of potassium added to the soil also affected the calcium content of tomato leaves as shown in Table 19. Leaves of plants supplied with the low level of potassium contained a significantly higher per cent calcium than leaves of plants grown with the high level of potassium. This table also shows the significant interaction between the levels of potassium and soil treatment. The effect of the interaction between levels of potassium and soil treatment on the percentage of calcium in plants is represented graphically in Fig. 13. Tomato plants grown in the D-D and check treatments reacted alike with the two levels of potassium. They contained high calcium percentages with the low potassium level and low calcium content with the high level of potassium. The Dowfume W-40 treated plants supplied with the two levels

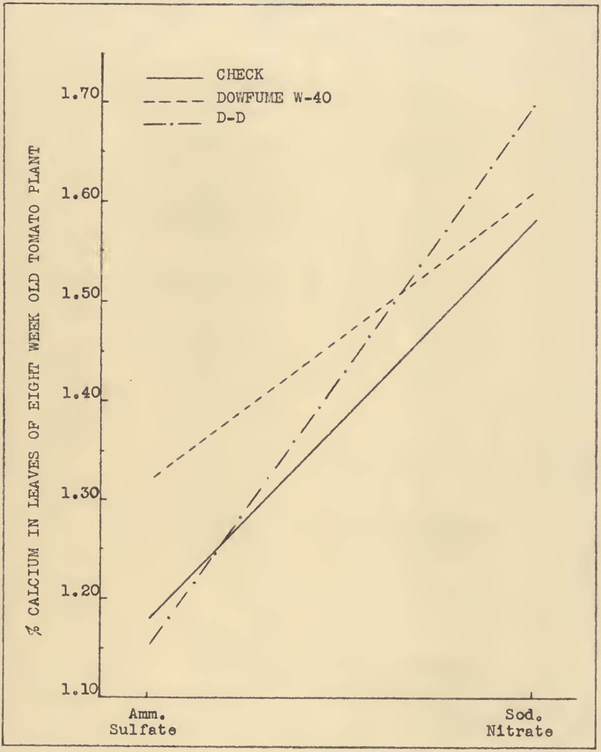

Fig.12. Effect of soil fumigation and source of nitrogen on the average per cent calcium in leaves of eight week old tomato plants.

TABLE 19

Effect of Soil Fumigation and Two Levels of Potassium on the Percentage of Calcium in Leaves of Eight Week Old Tomato Plants

Soil Fumigation	Levels of Potassium Low Level 10 ppm. of Soil	Levels of Potassium High Level 50 ppm. of Soil	Average for Soil Fumigation
Check	1.49	1.27	1.38
Dowfume W-40	1.43	1.50	1.46
D-D	1.53	1.32	1.42
Average for Levels of Potassium	1.48	1.36	

L.S.D. for soil fumigation averages

at: 5% level = .29 N.S.

L.S.D. for level of potassium averages

at: 5% level = .08

1% level = .11

L.S.D. for individuals

at: 5% level = .14

1% level = .19

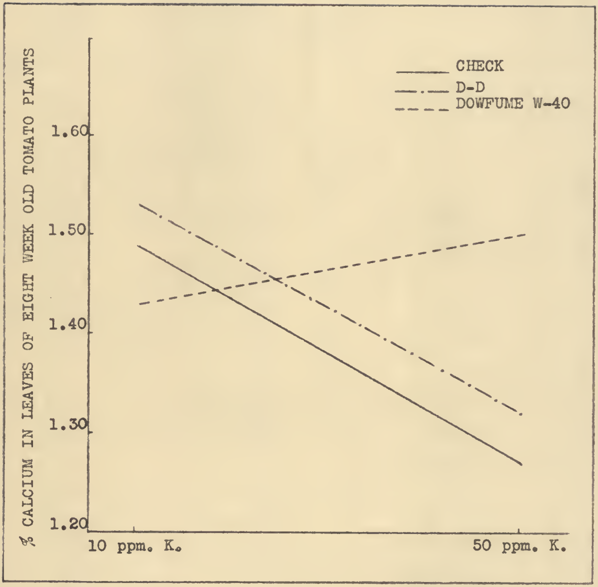

Fig.13. Effect of soil fumigation and levels of potassium on the average per cent calcium in leaves of eight week old tomato plants.

of potassium behaved in a different manner. The plants in the Dowfume W-40 treatment contained a lower percentage of calcium when supplied with a low level of potassium than when receiving the high level of potassium. It was also found that the interaction between the two sources of nitrogen and the two levels of potassium affected the calcium content of tomato leaves as shown in Table 20. Plants supplied with nitrate nitrogen and the low level of potassium were significantly higher in calcium content than plants receiving nitrate nitrogen and the high level of potassium. In plants receiving ammoniacal nitrogen, there were no significant differences in the calcium percentages when they were given either the low or high level of potassium.

The effect of the two sources of nitrogen on the percentage of total nitrogen, potassium, calcium and magnesium in the tomato leaves is represented graphically in Fig. 14. Tomato plants supplied with ammoniacal nitrogen were found after eight weeks to contain higher percentages of total nitrogen and potassium than plants fertilized with nitrate nitrogen. Calcium content of the tomato leaves was higher in plants receiving nitrate nitrogen than those supplied with ammoniacal nitrogen. There was no significant difference in magnesium content of plants when supplied with ammoniacal or nitrate nitrogen.

The analyses of variance for total nitrogen, potassium, magnesium, and calcium in tomato leaves is represented in

TABLE 20

Effect of Sources of Nitrogen and Levels of Potassium on the Percentage of Calcium in Leaves of Eight Week Old Tomato Plants

Levels of Potassium	Sources of Nitrogen		Average for Potassium Level
	Ammoniacal N	Nitrate N	
Low 10 ppm. of Soil	1.23	1.73	1.48
High 50 ppm. of Soil	1.20	1.53	1.36
Average for Sources of Nitrogen	1.22	1.63	

L.S.D. for source of nitrogen and level of potassium

averages at: 5% level = .08

1% level = .11

L.S.D. for individuals

at: 5% level = .11

1% level = .15

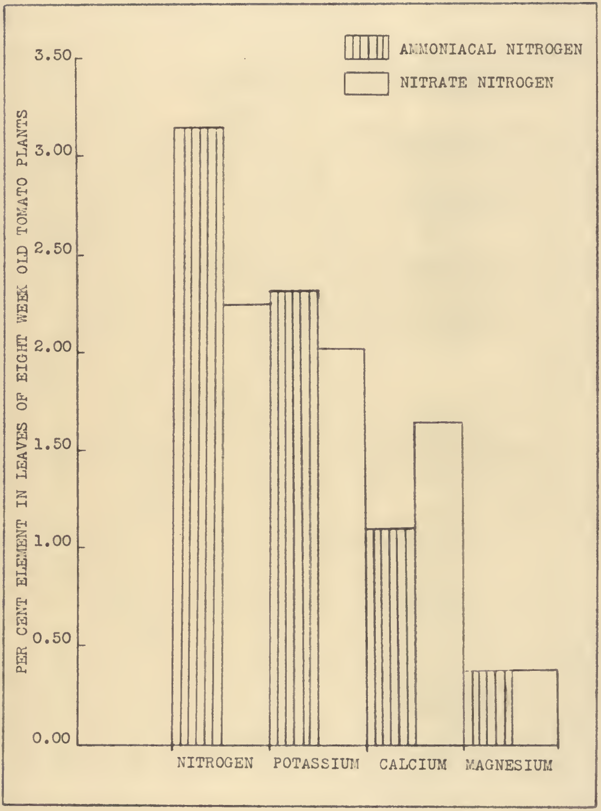

Fig.14. Effect of source of nitrogen on the average per cent total nitrogen, potassium, calcium and magnesium in leaves of eight week old tomato plants.

Table 21.

The effect of soil fumigation with Dowfume W-40 and D-D on the percentage of total nitrogen, potassium, calcium and magnesium in leaves of 8-week-old tomato plants is represented graphically in Fig. 15.

TABLE 21

Analysis of Variance for the Percentage of Total Nitrogen, Potassium, Magnesium and Calcium in Leaves of Eight Week Old Tomato Plants

Source of Variation	D.F.	Sum Squares Nitrogen Analysis	Potassium Analysis	Magnesium Analysis	Calcium Analysis
Grand Total	71	31.1675	16.2170	0.4414	7.2246
Main Treatment	8	6.1507	4.5698	0.0903	0.9830
Soil Fumigation	2	1.6598*	2.7662	0.0481*	0.0888
Replication	2	3.9704*	0.2422	0.0309	0.3835
Error "A"	4	0.5205	1.5614	0.0113	0.5107
Fertilization	7	15.2260	6.0946	0.0381	3.4793
Source of N.	1	14.6610**	1.4763**	0.0012	3.0669**
Levels of K.	1	0.0238	3.7950**	0.0043	0.2473**
Levels of Mg.	1	0.0378	0.0276	0.0064	0.0005
Source N. x Levels K.	1	0.0091	0.4851*	0.0133	0.1335*
Source N. x Levels Mg.	1	0.0013	0.2058	0.0003	0.0018
Levels K. x Levels Mg.	1	0.2300	0.0415	0.0022	0.0242
Source N. x K. x Mg.	1	0.2628	0.0630	0.0103	0.0050
Soil Fum. x Fert.	14	3.3850	2.0729	0.0883	1.5547**
Soil Fum. x Source N	2	1.0151*	0.3947	0.0308	0.2164*
Soil Fum. x K.	2	0.4121	0.1418	0.0308	0.2965**
Soil Fum. x Mg.	2	0.5478	0.5572*	0.0085	0.0149
Residual	8	1.4100	0.9792	0.0182	1.0269**
Error "B"	42	6.4058	3.4797	0.2247	1.2076

*Significance at: 5% level.

**Significance at: 1% level.

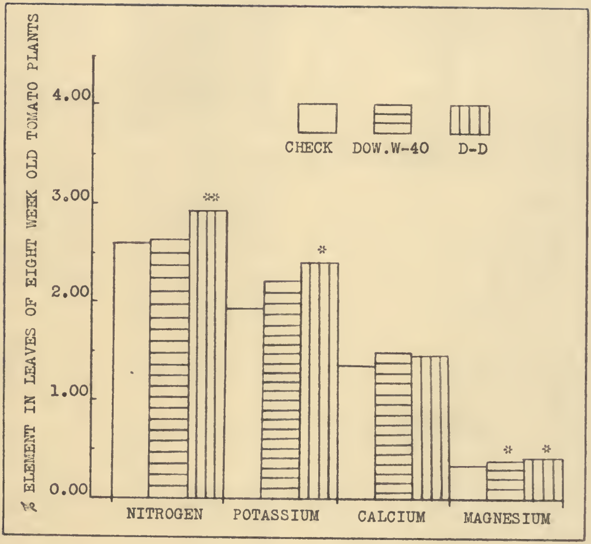

Fig.15. Effect of soil fumigation on the average per cent total nitrogen, potassium, calcium and magnesium in leaves of eight week old tomato plants.

* Significance at 5% level over the check.

** Significance at 1% level over the check.

PART III. Effect of Soil Fumigation on the Growth and Yield of Tomatoes Under Field Conditions

Materials and Methods

Practical application of soil fumigants was tested under field conditions with reference to source of nitrogen, magnesium and different rates of potassium application. The test was made with five main treatments. All main treatments were replicated four times, each replication consisting of 48 plants. These treatments were: (1) Check or no treatment; (2) D-D; (3) D-D with 2 per cent soluble magnesium applied in the fertilizer; (4) Dowfume W-40; and (5) Dowfume W-40 with 2 per cent soluble magnesium applied in the fertilizer. Each main treatment was sub-divided into four different treatments, as follows:

1. Nitrate nitrogen, derived from nitrate of soda, as the sole source of nitrogen in the fertilizer, plus 20 pounds of potash per acre.
2. Nitrate nitrogen, derived from nitrate of soda, as the sole source of nitrogen in the fertilizer plus 100 pounds of potash per acre.
3. Ammoniacal nitrogen, derived from sulfate of ammonia, as the sole source of nitrogen in the fertilizer, plus 20 pounds of potash per acre.
4. Ammoniacal nitrogen, derived from sulfate of

ammonia, as the sole source of nitrogen in the fertilizer, plus 100 pounds of potash per acre.

D-D and Dowfume W-40 were applied broadcast by the use of tractor-carried equipment. Two ten-gallon drums of material were mounted, one on each side of the tractor. From the bottom of each drum the fumigant flowed by gravity through ceram tubing to the rear of diamond-point cultivating tools mounted on the cultivator bar of the tractor. Four cultivating tools were used, spaced one foot apart on the bar and running at a depth of five to six inches. The quantity of fumigant applied was regulated by a system of double stopcocks connected to the tubing directly underneath the drum. The application of the fumigants was accomplished by adjusting the flow of the fumigant to the time it required the tractor to move a designated distance. D-D was applied at the rate of 174 ml. per 100 feet of row for each applicator tool, which corresponds to a rate of 20 gallons per acre. Dowfume W-40 was applied at the rate of 130 ml. per 100 feet of row per applicator tool, or 15 gallons per acre. The application of the fumigants was made 15 days prior to the planting on March 20. Fertilizer was applied at the time of planting by hand in bands to each side of the tomato row. The rate of application was 2,000 pounds per acre, using fertilizer with 4 per cent nitrogen, 7 per cent phosphoric acid and one of the two levels of potash tested.

Within one month after transplanting Rutgers tomatoes to the experimental plots, noticeable differences in growth and vigor of the plants were noted. On April 26, the height of 10 tomato plants from each sub-plot was measured.

The harvesting of tomatoes was begun on May 25 and continued until June 20. The yield of tomato fruit was good for the season with a minimum of leaf diseases, such as late blight. Plants were sprayed weekly with Zineb and DDT, each at ($\frac{1}{2}$ pound per 100 gallons of water).

On the completion of harvesting, three tomato plants were removed from each plot and a rating of the roots for nematode infestation made. This rating consisted of visually observing the relative amount of nematode damage as evidenced by the knotting of the roots. The roots were scored from 1 to 5. A score of 1 was used to designate very heavy infestations, 2, 3, and 4 showing correspondingly less, and 5 designating very slight infestations. The data obtained from this scoring method were subjected to statistical analysis.

Results and Discussion

Statistical analysis showed that soil treatment and source of nitrogen added to the soil affected the height of tomato plants significantly. Table 22 shows the effect of soil treatment, source of nitrogen and levels of potassium on the average height in inches of 10 tomato plants. Plants grown in D-D fumigated plots were significantly taller than those of the check plots. Comparing the average height of plants grown in D-D treatments with those from Dowfume W-40 treatments, significant differences in the height of plants were obtained, as shown in analysis of variance (Table 23). The addition of 2 per cent soluble magnesium did not affect the average height of the tomato plants.

The source of nitrogen is another factor which was found to have a highly significant effect on the growth of tomato plants. Plants supplied with nitrate nitrogen were significantly smaller in size than those fertilized with ammoniacal nitrogen. Some of this difference may be due to heavy rains which fell shortly after planting, causing leaching of nitrate nitrogen from the soil. The two levels of potassium used in this experiment were found to have no significant effect on the height of the plants.

The yield of No. 1 grade fruit was affected by soil treatment. Table 24 shows the effect of soil treatment, source of nitrogen and amount of potash on the average bushel

TABLE 22

Effect of Soil Treatment, Sources of Nitrogen, and Levels of Potassium on the Average Height (in Inches) of Tomato Plant

Main Treatment	Sub-Treatment Nitrate Nitrogen 20 lbs. K_2O per Acre	 Nitrate Nitrogen 100 lbs. K_2O per Acre	 Ammoniacal Nitrogen 20 lbs. K_2O per Acre	 Ammoniacal Nitrogen 100 lbs. K_2O per Acre	Main Treatment Averages
Check	7.5	7.0	10.3	10.3	8.8
D-D	9.7	9.3	10.6	10.7	10.1
D-D Mg.	9.5	8.5	10.4	10.5	9.7
Dowfume W-40	8.2	7.3	11.3	10.7	9.4
Dowfume W-40 Mg.	8.3	7.8	10.5	10.7	9.3
Sub-Treatment Averages	8.6	8.0	10.6	10.6	

L.S.D. for main treatment averages at: 5% level = .7
1% level = .9

L.S.D. for sub-treatment averages at: 5% level = .7
1% level = .9

TABLE 23

Analysis of Variance for Table 22

Source of Variation	D.F.	Sum Square	Mean Square	F. Value
Grand Total	79	206.76		
Main Plot	19	27.56		
Treatment	4	15.85	3.96	5.35**
Replication	3	2.85	.95	1.28
Error "A"	12	8.86	.74	
D-D and D-D plus Mg. vs. Dowfume W-40 and Dowfume W-40 plus Mg.	1	4.14	4.14	5.59*
Sub-Plot (Nutrient)	3	110.47	36.82	30.94**
Nitrogen Sources	1	106.03	106.03	89.10**
Potassium Levels	1	2.48	2.48	2.08
Potassium x Nitrogen	1	1.96	1.96	1.64
Nutrient x Treatment	12	15.32	1.28	1.07
Error "B"	45	53.41	1.19	

*Significant at 5% level.

**Significant at 1% level.

TABLE 24

The Effect of Soil Fumigation, Magnesium, Source of Nitrogen and Amount of Potash on Average Bushel Yield per Acre of No. 1 Tomatoes

Main Treatment	Sub-Treatment				Main Treatment Averages
	Nitrate Nitrogen		Ammoniacal Nitrogen		
	20 lbs. K_2O per Acre	100 lbs. K_2O per Acre	20 lbs. K_2O per Acre	100 lbs. K_2O per Acre	
Check	184.3	157.4	233.6	224.7	200.0
D-D	303.6	326.4	270.3	334.7	308.0
D-D plus 2% Mg. in Fertilizer	353.8	304.2	291.8	271.8	305.4
Dowfume W-40	223.4	160.2	236.1	256.8	219.1
Dowfume W-40 plus 2% Mg. in Fert.	244.8	187.1	231.5	252.7	229.0
Sub-Treatment Averages	262.0	227.1	252.7	268.1	

L.S.D. for main treatment averages at: 5% level = 43.2
1% level = 60.6

L.S.D. for sub-treatment averages at: 5% level = N.S.

yield per acre of No. 1 tomatoes. The plots treated with D-D produced significantly greater yields than those plots which were not treated or treated with Dowfume W-40. This table shows also that no differences in yield resulted from the use of 2 per cent soluble magnesium in the fertilizer. The yield of this grade of tomato was not affected as a result of the source of nitrogen or levels of potash tested.

The yield of No. 2 grade tomatoes was affected by soil treatment and source of nitrogen. Table 25 illustrates the effect of fumigation, magnesium, source of nitrogen and amounts of potash on the average yield per acre of No. 2 tomatoes. D-D treated plots produced a significantly greater yield of this grade of tomato than the Dowfume W-40 plots. These latter plots produced significantly higher yields than the untreated plots. No effect on yield was observed as a result of the use of soluble magnesium with either the D-D or Dowfume W-40 treatments. Nitrogen sources, however, did affect the yield of this grade and these results are shown in Table 26. An average higher yield of this grade of tomatoes was harvested from plots fertilized with ammoniacal nitrogen. No differences in yield were found between the two potash levels as shown in Table 27.

The total yield of the plots was analyzed statistically and significant difference in total yield of treated and untreated plots was obtained. Table 28 shows the effect

TABLE 25

The Effect of Soil Fumigation, Magnesium, Sources of Nitrogen and Amounts of Potash on Average Bushel Yield per Acre of No. 2 Tomato

Main Treatment	Sub-Treatment				Main Treatment Averages
	Nitrate Nitrogen		Ammoniacal Nitrogen		
	20 lbs. K_2O per Acre	100 lbs. K_2O per Acre	20 lbs. K_2O per Acre	100 lbs. K_2O per Acre	
Check	89.5	70.2	102.8	105.0	91.9
D-D	142.5	131.2	132.8	138.4	136.2
D-D 2% Mg. in Fertilizer	139.9	116.6	125.9	141.5	131.0
Dowfume W-40	106.6	80.1	123.4	136.6	111.7
Dowfume W-40 2% Mg. in Fertilizer	109.2	83.1	121.7	125.9	110.0
Sub-Treatment Averages	117.2	96.2	121.3	129.5	

L.S.D. for main treatment averages at: 5% level = 13.0
1% level = 18.2

L.S.D. for sub-treatment averages at: 5% level = 14.2
1% level = 18.9

TABLE 26

The Effect of Source of Nitrogen on the Average Bushel Yield per Acre of Tomatoes

Source of Nitrogen	Grade No. 1	Grade No. 2	Total
Nitrate of Soda	244.6	106.9	506.0
Sulfate of Ammonia	260.4	125.4	572.1
L.S.D. for averages at:			
5% level	N.S.	10.0	40.2
1% level	N.S.	13.4	53.7

TABLE 27

The Effect of Amount of Potash on the Average Bushel Yield per Acre of Tomatoes

Amount of Potash	Grade No. 1	Grade No. 2	Total
20 lbs. per Acre	257.4	119.4	539.8
100 lbs. per Acre	247.6	112.9	538.3
L.S.D. for averages at:			
5% level	N.S.	N.S.	N.S.

TABLE 28

The Effect of Soil Fumigation, Magnesium, Source of Nitrogen and Amount of Potash on the Average Total Bushel Yield per Acre of Tomatoes

Main Treatment	Sub-Treatment				Main Treatment Averages
	Nitrate Nitrogen		Ammoniacal Nitrogen		
	20 lbs. K_2O per Acre	100 lbs. K_2O per Acre	20 lbs. K_2O per Acre	100 lbs. K_2O per Acre	
Check	366.4	421.4	480.1	490.8	439.7
D-D	608.8	627.7	557.2	635.0	620.0
D-D plus 2% Mg. in Fertilizer	704.3	596.7	619.6	612.7	633.3
Dowfume W-40	481.9	353.6	540.2	622.1	499.5
Dowfume W-40 plus 2% Mg. in Fert.	492.1	406.6	547.3	565.8	503.0
Sub-Treatment Averages	530.7	481.2	548.9	595.3	

L.S.D. for main treatment averages at: 5% level = 74.8
1% level = 104.9

L.S.D. for sub-treatment averages at: 5% level = 56.9
1% level = 76.0

of fumigation, magnesium, source of nitrogen and amount of potash on the average total bushel yield per acre of tomatoes. D-D treated plots produced significantly higher yield than either the Dowfume W-40 plots or untreated plots. The Dowfume W-40 treatments yielded more than the untreated plots; however, the difference was not significant. The breakdown of the sub-treatments shows that yield was increased by the use of the ammoniacal nitrogen over the nitrate nitrogen as shown in Table 26. No differences in yield were found between the two levels of potash; however, Table 28 shows that the highest yield was obtained from the high level of potassium with the ammoniacal source of nitrogen.

Statistical analysis of the data obtained from the scoring of the roots showed significant differences in degree of infestation between treated and untreated plots. Table 29 shows the effect of soil treatment and fertilizer materials added to soil on the root-knot nematode infestation of the roots. Roots of plants grown in D-D fumigated soil were significantly less injured by nematodes than those grown in the Dowfume W-40 or untreated plots. Plants from untreated plots were very badly infested with root-knot nematodes.

The effect of soil treatment on the control of root-knot nematode in roots of tomato plants is shown in Plates VI, VII and VIII. Plate VI is a photograph of roots of three

TABLE 29

The Effect of Soil Fumigation and Fertilization on the Nematode Injury to Tomato Plant Roots Grown in Sandy Soil

Main Treatment	Sub-Treatment				Main Treatment Totals
	Nitrate Nitrogen		Ammoniacal Nitrogen		
	20 lbs. K_2O per acre	100 lbs. K_2O per Acre	20 lbs. K_2O per Acre	100 lbs. K_2O per Acre	
Check	4	6	5	5	20
D-D	15	14	13	14	56
D-D plus 2% Mg. in Fertilizer	16	11	13	15	55
Dowfume W-40	11	13	10	11	45
Dowfume W-40 plus 2% Mg. in Fert.	9	10	9	10	38
Sub-Treatment Totals	55	54	50	55	

L.S.D. for main treatment totals at: 5% level = 8
1% level = 12

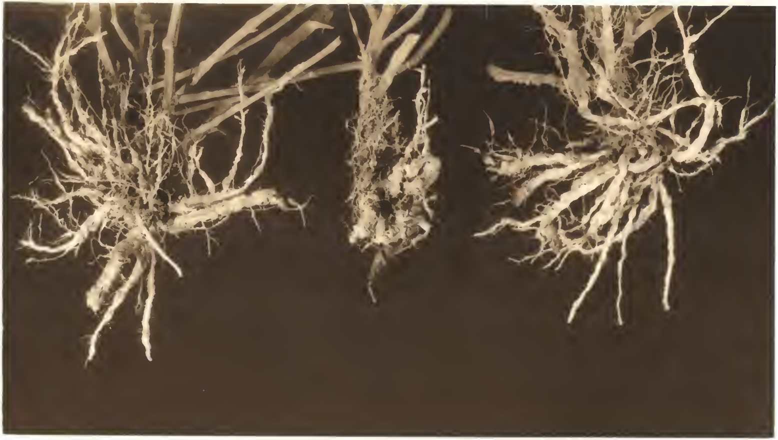

PLATE VI. Roots of Three Tomato Plants Showing Heavy Infestation of Root-Knot Nematode, Grown in Unfumigated Soil.

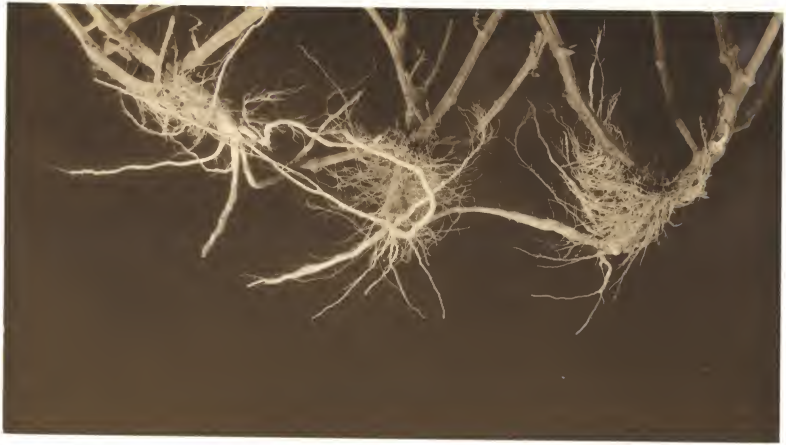

PLATE VII. Roots of Three Tomato Plants Grown in D-D Treated Soil.

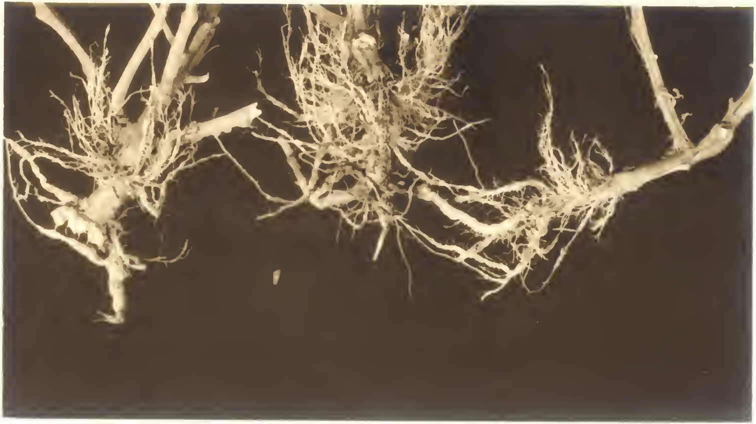

PLATE VIII. Roots of Three Tomato Plants Showing Medium Infestation of Root-Knot Nematode, Grown in Dowfume W-40 Treated Soil.

tomato plants showing heavy infestation of root-knot nematodes. These plants and those shown in Plates VII and VIII were grown in Arredondo loamy sand in the Spring of 1951. Plate VII shows the effect of D-D on the control of root-knot nematodes. Roots are almost free of galls. Plate VIII shows the roots of three tomato plants grown in Dowfume W-40 treatment. These roots were intermediate in root-knots between the check treatment and D-D. The degree of infestation of the tomato roots agreed to a great extent with the yield data previously discussed. Plants grown in D-D soil yielded significantly more than Dowfume W-40 treatment and, meanwhile showed least infestation. Dowfume W-40 treatments were intermediate in yield and degree of infestation between D-D and check treatment. Plate IX shows the relative degree of infestation on tomato roots grown in the three different soil treatments.

This experiment and other personal observations of soil fumigation treatments for the production of tomatoes has shown that the growth and yield is often affected. Other investigators have found that soil fumigation may affect the subsequent yield and quality of other field and vegetable crops. The efficient control of root-knot nematodes through the use of new soil fumigation materials has often resulted in remarkable increase in plant growth and higher yield. Steiner (42) attributed this increase in plant growth and

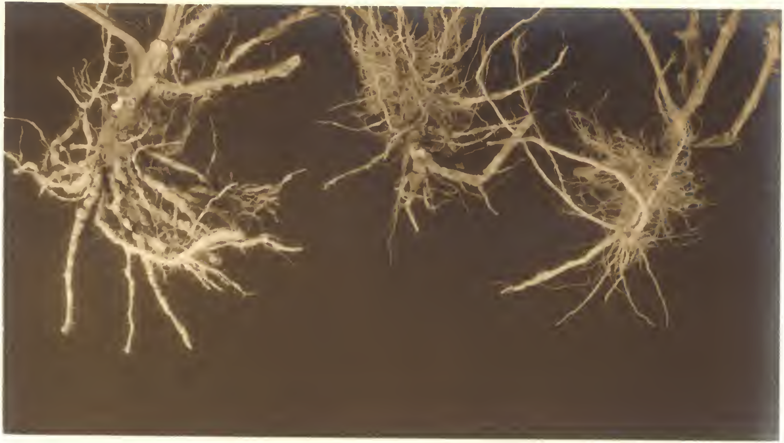

PLATE IX. Roots of Tomato Plants Grown in Different Soil Treatments.

Right to Left - D-D Treatment (Low Infestation);

Dowfume W-40 Treatment (Medium Infestation);

No Treatment (Heavy Infestation).

higher yield to a large extent to the partial destruction of the nematode population and the escape of young roots from the severe attack of the nematodes. Volk (43), working with cigar-wrapper tobacco in Florida, found that D-D was more effective in promoting persistence of ammonia in the soil following fertilization than Dowfume W-40, and the latter was significantly above the check. He stated, "The differences were such that the effect of fumigation on the ammonia level in the soil, and consequently on the plant, should be differentiated from the effect of control of nematodes in the soil for proper evaluation of the practice of fumigation for nematode control." Kidson and Stanton (19) studied the effect of steam, chloropicrin, and D-D on the ammonia and nitrate contents of glasshouse tomato soils. They found that high ammonia present in early stages of plant growth in certain treated plots did not affect the yield of the fruits. They concluded that the differences in available nitrogen between treated and untreated plots did not seem to be sufficient to account for the differences in yield and growth. Peters (33) stated that D-D has a beneficial effect on potato plants, even in the absence of nematode infection. A recent work by Miller (25) on the effect of ethylene dibromide soil treatment on root-knot control, nodulation, and yield of peanuts showed that ethylene dibromide increased plant growth and nodulation of the peanuts.

He stated that root-knot control or better nodulation or a combination of the two would seem to account for the increased plant development. He concluded, "It is not possible to evaluate the actual effect of the treatment until more extensive tests are conducted under controlled conditions."

Smith (40), on the other hand, working with D-D for controlling nematodes of cotton, found that D-D applied at the rate of 14 gallons per acre gave abnormal plant type and growth. He said, "This resulted, presumably, from nitrogen stimulation as a result of treatment." Clayton and Ellis (8) found that chloropicrin and D-D, although they gave a good control of root-knot nematodes on beans, have a toxic or deleterious effect on growth and yield.

SUMMARY AND CONCLUSIONS

Part I. Effect of Soil Fumigation on Soil Nitrification

1. This work was conducted to study the effect of some soil fumigant materials principally used for the control of root-knot nematode on the nitrification power of the soil. An indirect method was used in this study, in that the amount of nitrates converted by the nitrifying organisms in the soil was measured quantitatively.

2. Results indicate that D-D and Dowfume W-40 checked the growth of the nitrifying organisms in the soil. The conversion of ammonium sulfate, added to the soil, to nitrates was very slow after soil treatments.

3. D-D had a more inhibiting effect on the nitrifying organisms in the soil than Dowfume W-40.

4. The effect of D-D treatment on the nitrifying organisms of the soil lasted longer than Dowfume W-40 treatment.

5. The three levels of soil fumigants, 1, 2.5 and 4 ml. per square foot, added to the soil, did not differ in their effect on the nitrification power of the soil except in one case. Plots treated with D-D at the rate of 4 ml. per square foot were significantly lower in nitrate nitrogen content at the end of 10 weeks than those receiving the other

treatments.

Part II. Effect of Soil Fumigation on Tomato Plant Behavior

1. This phase of the work was a greenhouse study where an attempt was made to study the effect of soil fumigation on the growth and chemical composition of tomato plants, when the plants were supplied with different sources of nitrogen and different amounts of potassium and magnesium. Two experiments were conducted in this phase; in the first one the plants were transplanted one week after soil treatment, and in the second transplanting was done two weeks after soil treatment.

2. Tomato plants transplanted one week after soil treatment were markedly affected by the treatment with D-D which checked the growth of the plants and resulted in light green color of the leaves. The Dowfume W-40 treatment did not affect the growth of the plants as much as the D-D treatment. Making three holes four inches deep in the soil of each pot helped the plants grown in the D-D and Dowfume W-40 treated soils to recover and to start new green growth. Examination of the roots four weeks after transplanting, showed that a portion of the main root was without secondary roots. This phenomenon was more pronounced in the D-D treatment than in the Dowfume W-40 treatment. It seems that delayed diffusion of D-D from the soil inhibited the differentiation of secondary roots and, consequently, resulted in

slower growth. Plants transplanted two weeks after soil treatment grew normally.

3. Plants grown in fumigated soil contained more total nitrogen in their leaves than those grown in untreated soil. D-D was more effective in increasing the total nitrogen of the leaves than Dowfume W-40.

4. Plants supplied with an ammoniacal source of nitrogen were much higher in total nitrogen of the leaves than those receiving nitrate nitrogen.

5. Leaves of plants grown in D-D fumigated soil were higher in their potassium content than those grown in untreated soil especially when the plants were four weeks old.

6. The source of nitrogen added to the soil seems to affect the potassium and calcium contents of the leaves. Plants supplied with ammonium sulfate contained a much higher percentage of potassium and a lower percentage of calcium in their leaves than those receiving nitrate nitrogen. On the other hand, the calcium content of the leaves showed the opposite. Plants receiving ammonium sulfate contained a lower percentage of calcium in their leaves than those supplied with nitrate nitrogen.

7. Soil fumigation resulted in an increase in the magnesium content of plant leaves, especially when the plants were eight weeks old.

8. Although soil treatment had no effect on the

calcium content of the leaves, the interaction between soil treatment and the source of nitrogen affected the calcium content of the leaves when the plants were four weeks old. Tomato plants grown under the three different soil treatments did not respond alike in their calcium content with the two sources of nitrogen applied to the soil. There was no significant difference in calcium content of leaves in ammonia fertilized plants under the three soil treatments. However, the difference in calcium content of the leaves of nitrate supplied plants was significant under the three soil treatments. Nitrate nitrogen fertilized plants grown in D-D fumigated soil contained higher percentages of calcium than those in unfumigated soils.

9. The levels of magnesium supplied in the fertilizer did not seem to have any effect on the amount of total nitrogen, potassium, magnesium and calcium in plant leaves.

10. Levels of potassium added to the soil affected the calcium content of the leaves of eight week old tomato plants. Plants supplied with the low level of potassium contained significantly more calcium than those receiving no potassium.

Part III. Effect of Soil Fumigation on the Growth and Yield Under Field Conditions

1. Practical application of soil fumigants was

tested under field conditions with reference to source of nitrogen, magnesium and different rates of potassium application.

2. Soil fumigation with D-D and Dowfume W-40 resulted in an increase in plant growth, and D-D was superior to Dowfume W-40 in this regard.

3. The D-D treatment produced a larger total yield than either the untreated soil or the Dowfume W-40 treatment.

4. The total yield was greater where ammonium sulphate was used to supply nitrogen than where nitrate of soda was used.

5. No differences in total yield were found between the two levels of potassium, 20 and 100 lbs. per acre. The use of 2 per cent of soluble magnesium in the fertilizer also had no effect on yield.

6. Plots treated with D-D produced significantly greater yields of grade No. 1 tomatoes than those plots which were not treated or were treated with Dowfume W-40.

7. There was no significant difference in grade No. 1 tomatoes between nitrate of soda or sulfate of ammonia. However, the use of ammonium sulfate resulted in greater yield of grade No. 2 tomatoes than nitrate of soda.

8. Soil fumigants reduced the root-knot infestation of the tomato roots, with D-D causing greater reduction than Dowfume W-40 treatment.

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BIOGRAPHICAL ITEMS

Said Hamdi was born in May, 1924, in the beautiful city of Alexandria, Egypt. He received his primary education in Ramleh primary school and his secondary education in Abbassieh High School, Alexandria, Egypt. In October, 1941, he entered Fouad I University and received his B.A. in June, 1945. He worked at Farouk I University, Alexandria, Egypt, as assistant teacher in the College of Agriculture from February, 1946, until November, 1948. He was granted a study leave and a scholarship from Farouk I University to continue advanced studies in the field of horticulture and entered the University of Florida in February, 1949. Since then he has pursued his studies toward a Ph.D. degree in Horticulture at the University of Florida in Gainesville. His doctoral research was conducted in cooperation with the Florida Agricultural Experiment Station at Gainesville.

This dissertation was prepared under the direction of the Chairman of the candidate's Supervisory Committee and has been approved by all members of the committee. It was submitted to the Graduate Council and was approved as a partial fulfilment of the requirements for the degree of Doctor of Philosophy.

February 2, 1952

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